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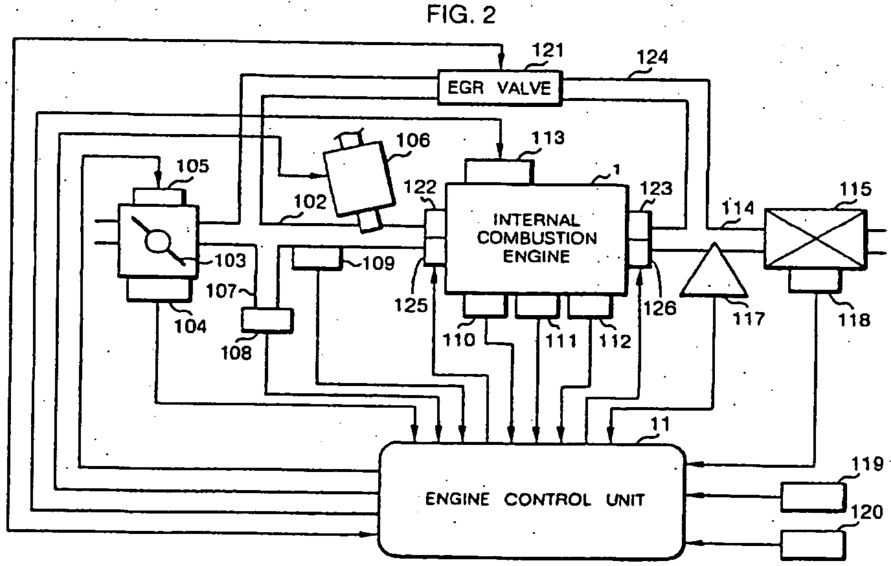
(54) Control system for hybrid vehicle

(57) A control system controls a hybrid vehicle having an engine (1) for rotating a drive axle (2), an electric motor (3) for converting kinetic energy of the drive axle (2), into electric energy in a regenerative mode, a drive control circuit for controlling the electric motor (3), and electric energy storage means (14) for storing electric energy. The control system has an intake air control unit (105) for controlling an amount of intake air supplied to the engine (1), and an exhaust gas recirculation control valve (121) for controlling recirculation of exhaust gases from an exhaust system of the engine (1) to an intake system of the engine (1). A control unit (11) operates the intake air control unit (105) to reduce the amount of intake air and operates the exhaust gas recirculation control valve (121) in an opening direction when the electric motor (3) operates in the regenerative mode while the hybrid vehicle is decelerating.

FIG. 2



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Description

[0001] The present invention relates to a control system for controlling a hybrid vehicle having an internal combustion engine and an electric motor as separate propulsion sources, and more particularly to a control system for controlling a hybrid vehicle in regenerating electric energy with an electric motor.

[0002] There have heretofore been known hybrid vehicles each having an internal combustion engine and an electric motor as separate propulsion sources. There has also been proposed a control system for controlling a hybrid vehicle to increase the regenerative efficiency of an electric motor when it operates in a regenerative mode at the time the hybrid vehicle is decelerating. For example, a control system disclosed in Japanese laid-open patent publication No. 8-112190 fully opens an electrically controlled throttle valve when the electric motor operates in the regenerative mode at the time the hybrid vehicle is decelerating. The amount of intake air supplied to the engine is thus made greater than when the throttle valve remains closed in the regenerative mode. Accordingly, a mechanical energy loss due to pumping losses of the engine is reduced, and the kinetic energy of the hybrid vehicle can efficiently be recovered as regenerated energy.

[0003] However, when the throttle valve is fully opened in the regenerative mode, a large amount of cold fresh air flows through the engine into its exhaust system. The introduced cold fresh air cools a three-way catalytic converter in the exhaust system, tending to impair emission characteristics of the three-way catalytic converter.

[0004] The present invention therefore seeks to provide a control system for controlling a hybrid vehicle having an internal combustion engine and an electric motor to reduce pumping losses of the engine to increase the regenerative efficiency when the kinetic energy of the hybrid vehicle is converted into electric energy in a regenerative mode when the hybrid vehicle is decelerating, and to reduce the influx of air into an exhaust system of the engine for thereby preventing a reduction in the temperature of a catalytic converter in the exhaust system and also preventing emission characteristics of the catalytic converter from being impaired.

[0005] The present invention also seeks to provide a control system for reducing pumping losses of an internal combustion engine of a hybrid vehicle by controlling an exhaust gas recirculation valve which controls the recirculation of exhaust gases from an exhaust pipe to an intake pipe of the engine.

[0006] The present invention also seeks to provide a control system for reducing pumping losses of an internal combustion engine of a hybrid vehicle by controlling an intake valve or an exhaust valve.

[0007] The present invention also seeks to provide a control system for controlling an exhaust gas recirculation valve, an intake valve, or an exhaust valve for reducing pumping losses of an internal combustion engine of a hybrid vehicle, based on a regeneration limiting quantity.

[0008] According to a first aspect of the present invention there is provided a control system for controlling a hybrid vehicle having an engine for rotating a drive axle, an electric motor for converting kinetic energy of the drive axle into electric energy in a regenerative mode, a drive control circuit for controlling the electric motor, and electric energy storage means for storing electric energy, comprising intake air control means for controlling an amount of intake air supplied to the engine, an exhaust gas recirculation control valve for controlling recirculation of exhaust gases from an exhaust system of the engine to an intake system of the engine, and control means for operating the intake air control means to reduce the amount of intake air and operating the exhaust gas recirculation control valve in an opening direction when the electric motor operates in the regenerative mode while the hybrid vehicle is decelerating.

[0009] The control system further comprises regenerative quantity establishing means for establishing a regenerative quantity depending on a vehicle speed of the hybrid vehicle when the hybrid vehicle is decelerating, and regeneration limiting quantity establishing means for establishing a regeneration limiting quantity to limit the regenerative quantity depending on a remaining capacity of the electric energy storage means, the control means comprising means for operating the exhaust gas recirculation control valve in a closing direction based on the regeneration limiting quantity established by the regeneration limiting quantity establishing means.

[0010] According to a second aspect of the present invention, there is provided a control system for controlling a hybrid vehicle having an engine for rotating a drive axle, an electric motor for converting kinetic energy of the drive axle into electric energy in a regenerative mode, a drive control circuit for controlling the electric motor, and electric energy storage means for storing electric energy, comprising intake air control means for controlling an amount of intake air supplied to the engine, intake valve actuating means for actuating an intake valve of the engine, and control means for operating the intake air control means to reduce the amount of intake air and controlling the intake valve actuating means to operate the intake valve in an opening direction when the electric motor operates in the regenerative mode while the hybrid vehicle is decelerating.

[0011] According to a third aspect of the present invention, there is provided a control system for controlling a hybrid vehicle having an engine for rotating a drive axle, an electric motor for converting kinetic energy of the drive axle into electric energy in a regenerative mode, a drive control circuit for controlling the electric motor, and electric energy storage means for storing electric energy, comprising intake air control means for controlling an amount of intake air supplied to the engine, exhaust valve actuating means for actuating an exhaust valve of the engine, and control means

for operating the intake air control means to reduce the amount of intake air and controlling the exhaust valve actuating means to operate the exhaust valve in an opening direction when the electric motor operates in the regenerative mode while the hybrid vehicle is decelerating.

[0012] According to a fourth aspect of the present invention, there is provided a control system for controlling a hybrid vehicle having an engine for rotating a drive axle and an electric motor for converting kinetic energy of the drive axle into electric energy in a regenerative mode, comprising intake valve actuating means for actuating an intake valve of the engine, exhaust valve actuating means for actuating an exhaust valve of the engine, and control means for operating the intake valve actuating means and the exhaust valve actuating means to operate the intake valve and the exhaust valve in a closing direction when the electric motor operates in the regenerative mode while the hybrid vehicle is decelerating.

[0013] For a better understanding of the present invention and to show how the same may be carried into effect, reference will now be made, by way of example, to the accompanying drawings, in which:-

BRIEF DESCRIPTION OF THE DRAWINGS

[0014]

FIG. 1 is a block diagram of a drive apparatus of a hybrid vehicle and a control system therefor according to the present invention;
FIG. 2 is a block diagram of an engine control arrangement of the control system;
FIG. 3 is a block diagram of an electric motor control arrangement of the control system;
FIG. 4 is a block diagram of a transmission control arrangement of the control system;
FIGS. 5 and 6 are a flowchart of a processing sequence for calculating an output power to be generated by an electric motor, and determining output power distributions for the electric motor and an engine with respect to a demand drive power;
FIG. 7 is a diagram showing the relationship between the remaining capacity of an electric energy storage unit and the output power distribution of the electric motor;
FIG. 8 is a diagram showing the relationship between the amount of operation of an accelerator pedal and the opening of a throttle valve;
FIG. 9 is a diagram showing the relationship between the opening of the throttle valve and the output power distribution of the electric motor;
FIG. 10 is a diagram showing a table for establishing demand drive powers;
FIG. 11 is a diagram showing a table for establishing running status quantities;
FIG. 12 is a diagram showing a table of running resistances RUNRST;
FIG. 13 is a diagram showing the relationship between the output power of the electric motor and a torque command for the electric motor;
FIG. 14 is a flowchart of an overall engine control processing sequence;
FIGS. 15 and 16 are a flowchart of a processing sequence for determining a decelerating regenerative quantity according to a first embodiment of the present invention;
FIG. 17 is a diagram showing a table of desired running resistances RUNRSTcom;
FIG. 18 is a diagram showing a REGperml table;
FIG. 19 is a diagram showing a REGperm2 table;
FIG. 20 is a schematic view showing the manner in which an exhaust gas recirculation system operates according to the first embodiment of the present invention;
FIG. 21 is a flowchart of a portion of a processing sequence for determining a decelerating regenerative quantity according to a second embodiment of the present invention;
FIG. 22 is a schematic view showing the manner in which an exhaust gas recirculation system operates according to the second embodiment of the present invention;
FIG. 23 is a flowchart of a portion of a processing sequence for determining a decelerating regenerative quantity according to a third embodiment of the present invention; and
FIG. 24 is a schematic view showing the manner in which an exhaust gas recirculation system operates according to the third embodiment of the present invention.

[0015] FIG. 1 shows in block form a drive apparatus of a hybrid vehicle and a control system therefor according to the present invention. Other components of the hybrid vehicle, including sensors, actuators, etc., are omitted from illustration in FIG. 1.

[0016] As shown in FIG. 1, the hybrid vehicle has a multicylinder internal combustion engine 1 which rotates a drive axle 2 for rotating drive wheels 5 (only one shown) through a transmission mechanism 4. An electric motor 3 is con-

nected to rotate the drive axle 2 directly. In addition to the ability to rotate the drive axle 2, the electric motor 3 has a regenerative ability to convert kinetic energy produced by the rotation of the drive axle 2 into electric energy. The electric motor 3 is connected to an ultracapacitor (a capacitor having a large electrostatic capacitance) 14 serving as an electric energy storage unit through a power drive unit 13. The electric motor 3 is controlled by the power drive unit 13 to rotate the drive axle 2 and generate electric energy in a regenerative mode.

[0017] The control system also has an engine control unit 11 for controlling the engine 1, an electric motor control unit 12 for controlling the electric motor 3, an energy distribution control unit 15 for carrying out energy management based on a determined status of the ultracapacitor 14, and a transmission control unit 16 for controlling the transmission mechanism 4. The engine control unit 11, the electric motor control unit 12, the energy distribution control unit 15, and the transmission control unit 16 are connected to each other through a data bus 21 for exchanging detected data, flags, and other information.

[0018] FIG. 2 shows the engine 1, the engine control unit 11, and ancillary devices thereof. A throttle valve 103 is mounted in an intake pipe 102 connected to the engine 1, and a throttle valve opening sensor 104 is coupled to the throttle valve 103 for generating an electric signal representative of the opening of the throttle valve 103 and supplying the generated electric signal to the engine control unit 11. A throttle actuator 105 for electrically controlling the opening of the throttle valve 103 is coupled to the throttle valve 103. The throttle actuator 105 is controlled in its operation by the engine control unit 11.

[0019] A portion of the intake pipe 102 downstream of the throttle valve 13 is connected to an exhaust pipe 114 through an exhaust gas recirculation passage 124 which has an exhaust gas recirculation (EGR) control valve 121 for controlling the amount of exhaust gases flowing through the exhaust gas recirculation passage 124.

[0020] The EGR control valve 121 comprises a solenoid-operated valve having a solenoid electrically connected to the engine control unit 11. The valve opening of the EGR control valve 121 can be varied by a control signal that is supplied from the engine control unit 11 to the solenoid of the EGR control valve 121.

[0021] An intake pipe absolute pressure (Pba) sensor 108 is connected to the intake pipe 102 through a pipe 107 immediately downstream of the throttle valve 103. The intake pipe absolute pressure sensor 108 generates an electric signal representative of an absolute pressure in the intake pipe 102, and supplies the generated signal to the engine control unit 11.

[0022] An intake temperature sensor 109 is mounted on the intake pipe 102 downstream of the intake pipe absolute pressure sensor 108. The intake temperature sensor 109 generates an electric signal representative of the temperature of intake air flowing in the intake pipe 102 and supplies the generated signal to the engine control unit 11.

[0023] Fuel injection valves 106 are mounted in the intake pipe 102 at respective positions downstream of the throttle valve 103 and slightly upstream of respective intake valves 122 disposed respectively in the cylinders of the engine 1. The fuel injection valves 106 are connected through a pressure regulator (not shown) to a fuel tank (not shown). The fuel injection valves 106 are electrically connected to the engine control unit 11, which applies signals to the fuel injection valves 106 to control times to open and close the fuel injection valves 106.

[0024] An engine coolant temperature sensor 110, which may comprises a thermistor or the like, is mounted on the cylinder block of the engine 1. The engine coolant temperature sensor 110 generates an electric signal representative of the engine coolant temperature and supplies the generated signal to the engine control unit 11.

[0025] An engine rotational speed (NE) sensor 111 is mounted near a camshaft or crankshaft (not shown) of the engine 1. The engine rotational speed sensor 111 generates a signal pulse at a predetermined crankshaft angle (hereinafter referred to as a "TDC signal pulse") each time the crankshaft of the engine 1 makes a 180° turn, and supplies the TDC signal pulse to the engine control unit 11.

[0026] The engine 1 has ignition plugs 113 positioned at the respective cylinders and electrically connected to the engine control unit 11, which controls the ignition timing of the ignition plugs 113.

[0027] The intake valves 122 are disposed respectively in intake ports (not shown) that open into combustion chambers (not shown) of the engine 1 and are connected to the intake pipe 102. Intake valve actuators 125 are coupled to the respective intake valves 122 for keeping the intake valves 122 open or closed and also for controlling the lift and valve opening periods of the intake valves 122. The intake valves 122 can be mechanically operated by a cam shaft (not shown), and also electromagnetically operated by the intake valve actuators 125 out of synchronism with the rotation of the engine 1. The intake valve actuators 125 are controlled for their operation by the engine control unit 11.

[0028] Exhaust valves 123 are disposed respectively in exhaust ports (not shown) that open into the combustion chambers of the engine 1 and are connected to the exhaust pipe 114. Exhaust valve actuators 126 are coupled to the respective exhaust valves 123 for keeping the exhaust valves 123 open or closed and also for controlling the lift and valve opening periods of the exhaust valves 123. The exhaust valves 123 can be mechanically operated by a cam shaft (not shown), and also electromagnetically operated by the exhaust valve actuators 126 out of synchronism with the rotation of the engine 1. The exhaust valve actuators 126 are controlled for their operation by the engine control unit 11.

[0029] A three-way catalytic converter 115 for purifying toxic components, including HC, CO, NOx, etc. of exhaust

gases emitted from the engine 1 is mounted in an exhaust pipe 114 connected to the engine 1. An air-fuel ratio sensor 117 is mounted on the exhaust pipe 114 upstream of the three-way catalytic converter 115. The air-fuel ratio sensor 117 generates an electric signal substantially proportional to the concentration of oxygen (and the shortage of oxygen) in the exhaust gases, and supplies the generated signal to the engine control unit 11. The air-fuel ratio sensor 117 can detect the air-fuel ratio of an air-fuel mixture supplied to the engine 1 through a wide range of air-fuel ratios ranging from a theoretical air-fuel ratio to lean and rich values.

[0030] A catalyst temperature sensor 118 is mounted on the three-way catalytic converter 115 for detecting the temperature thereof. The catalyst temperature sensor 118 supplies an electric signal representative of the detected temperature to the engine control unit 11. A vehicle speed sensor 119 for detecting the speed Vcar of the hybrid vehicle and an accelerator opening sensor 120 for detecting the depression (hereinafter referred to as an "accelerator opening") θap of the accelerator pedal are electrically connected to the engine control unit 11. Electric signals generated by the vehicle speed sensor 119 and the accelerator opening sensor 120 are supplied to the engine control unit 11.

[0031] A sensor 112 is mounted on the internal combustion engine 1 for generating a pulse each time the crankshaft turns through a predetermined angle. A pulse signal generated by the sensor 112 is supplied to the engine control unit 11, which identifies an engine cylinder into which fuel is to be injected, based on the supplied pulse signal.

[0032] The engine control unit 11 comprises an input circuit for shaping the waveforms of input signals from the above various sensors, correcting the voltage levels thereof into predetermined levels, and converging analog signals into digital signals, a central processing unit (hereinafter referred to as a "CPU"), a memory for storing various processing programs to be executed by the CPU and various processed results, and an output circuit for supplying drive signals to the fuel injection valves 106 and the ignition plugs 113. The other control units including the electric motor control unit 12, the energy distribution control unit 15, and the transmission control unit 16 are structurally similar to the engine control unit 11.

[0033] FIG. 3 shows a connected arrangement of the electric motor 3, the power drive unit 13, the ultracapacitor 14, the electric motor control unit 12, and the energy distribution control unit 15.

[0034] As shown in FIG. 3, the electric motor 3 is associated with an electric motor rotational speed sensor 202 for detecting the rotational speed of the electric motor 3. An electric signal generated by the electric motor rotational speed sensor 202 as representing the rotational speed of the electric motor 3 is supplied to the electric motor control unit 12. The power drive unit 13 and the electric motor 3 are interconnected by wires connected to a current-voltage sensor 201 which detects a voltage and a current supplied to or outputted from the electric motor 3. A temperature sensor 203 for detecting the temperature of the power drive unit 13, more specifically, the temperature TD of a protective resistor of a drive circuit for the electric motor 3, is mounted on the power drive unit 13. Detected signals from the sensors 201, 203 are supplied to the electric motor control unit 12.

[0035] The ultracapacitor 14 and the power drive unit 13 interconnected by wires connected to a current-voltage sensor 204 for detecting a voltage across the ultracapacitor 14 and a current outputted from or supplied to the ultracapacitor 14. A detected signal from the current-voltage sensor 204 is supplied to the energy distribution control unit 15.

[0036] FIG. 4 shows a connected arrangement of the transmission mechanism 4 and the transmission control unit 16. The transmission mechanism 4 is associated with a gear position sensor 301 for detecting a gear position of the transmission mechanism 4. A detected signal from the gear position sensor 301 is supplied to the transmission control unit 16. In the illustrated embodiment, the transmission mechanism 4 comprises an automatic transmission mechanism, and is also associated with a transmission actuator 302 which is controlled by the transmission control unit 16 to change gear positions of the transmission mechanism 4.

[0037] FIGS. 5 and 6 shows a processing sequence for calculating an output power to be generated by the electric motor 3 based on a demand drive power, i.e., a drive power which the drive of the hybrid vehicle demands, and determining output power distributions for the electric motor 3 and the engine 1 with respect to the demand drive power. The processing sequence shown in FIGS. 5 and 6 is executed by the energy distribution control unit 15 in each periodic cycle.

[0038] In FIG. 5, the energy distribution control unit 15 detects a remaining capacity of the ultracapacitor 14 in STEP1. Specifically, the energy distribution control unit 15 integrates an output current from the ultracapacitor 14 and an output current (charging current) to the ultracapacitor 14 at each periodic interval, and calculates an integrated discharged value CAPdis (positive value) and an integrated charged value CAPchg (negative value). The energy distribution control unit 15 then calculates a remaining capacity CAPrem of the ultracapacitor 14 according to the following equation (1):

$$\mathrm{CAPrem} = \mathrm{CAPful} - (\mathrm{CAPdis} + \mathrm{CAPchg}) \qquad (1)$$

where CAPful represents a dischargeable quantity when the ultracapacitor 14 is fully charged.

[0039] The energy distribution control unit 15 corrects the calculated remaining capacity CAPrem based on an internal resistance of the ultracapacitor 14 which varies with temperature, etc., thereby determining a final remaining capacity

of the ultracapacitor 14.

[0040] Instead of calculating the remaining capacity of the ultracapacitor 14 as described above, the remaining capacity of the ultracapacitor 14 may be determined by detecting an open-circuit voltage across the ultracapacitor 14.

[0041] In STEP2, the energy distribution control unit 15 determines an output power distribution quantity for the electric motor 3, i.e., a drive power PRATIO to be generated by the electric motor 3, of a demand drive power POWERcom, using an output power distribution ratio table. The drive power PRATIO is expressed as a ratio to the demand drive power, and will hereinafter be referred to as a "distribution ratio PRATIO".

[0042] FIG. 7 shows the output power distribution ratio table by way of example. The output power distribution ratio table is in the form of a graph having a horizontal axis which represents the remaining capacity of the ultracapacitor 14 and a vertical axis which represents the distribution ratio PRATIO. The output power distribution ratio table contains predetermined distribution ratios PRATIO with respect to remaining capacities, where the charging and discharging efficiency of the ultracapacitor 14 is maximum.

[0043] In STEP3, the energy distribution control unit 15 determines a command (hereinafter referred to as a "throttle valve opening command") θthCOM for the throttle actuator 105, corresponding to an accelerator opening θap detected by the accelerator opening sensor 120, from an accelerator vs. throttle characteristic table shown in FIG. 8.

[0044] The accelerator vs. throttle characteristic table shown in FIG. 8 is in the form of a graph having a horizontal axis which represents the accelerator opening θap and a vertical axis which represents the throttle valve opening command θthCOM. In FIG. 8, values of the accelerator opening θap are equal to corresponding values of the throttle valve opening command θthCOM. However, values of the accelerator opening θap may be different from corresponding values of the throttle valve opening command θthCOM.

[0045] In STEP4, the energy distribution control unit 15 determines a distribution ratio PRATIOth for the electric motor 3 corresponding to the determined throttle valve opening command θthCOM from a throttle vs. motor output power ratio table shown in FIG. 9.

[0046] The throttle vs. motor output power ratio table shown in FIG. 9 is in the form of a graph having a horizontal axis which represents the throttle valve opening command θthCOM and a vertical axis which represents the distribution ratio PRATIOth. In FIG. 9, the throttle vs. motor output power ratio table is established such that the output power, which is indicated by the distribution ratio PRATIOth, generated by the electric motor 3 is increased when the throttle valve opening command θthCOM is 50 degrees or higher, for example.

[0047] While the distribution ratio PRATIOth is determined depending on the throttle valve opening command θthCOM in the illustrated embodiment, the distribution ratio PRATIOth may be determined depending on one or more parameters representing the vehicle speed, the engine rotational speed, etc.

[0048] In STEP5, the energy distribution control unit 15 determines a demand drive power POWERcom depending on the throttle valve opening command θthCOM and the engine rotational speed NE from a demand drive power map shown in FIG. 10.

[0049] The demand drive power map shown in FIG. 10 is a map for determining a demand drive power POWERcom which the driver of the hybrid vehicle demands. The demand drive power map shown in FIG. 10 contains values of the demand drive power POWERcom depending on values of the throttle valve opening command θthCOM or the accelerator opening θap and values of the engine rotational speed NE.

[0050] In STEP6, the energy distribution control unit 15 calculates a corrective term θthADD for the throttle valve opening for generating the demand drive power POWERcom (θthADD = θthCOM - θthi (previous throttle valve opening)). In STEP7, the energy distribution control unit 15 determines a running status quantity VSTATUS depending on the vehicle speed Vcar detected by the vehicle speed sensor 119 and an extra output power POWERex of the engine 1 from a table for establishing running status quantities shown in FIG. 11. The running status quantity VSTATUS is greater as the vehicle speed Vcar is higher and the extra output power POWERex is greater.

[0051] The extra output power POWERex of the engine 1 is calculated according to the following equation (2):

$$\mathrm{POWERex} = \mathrm{POWERcom} - \mathrm{RUNRST} \qquad (2)$$

where RUNRST represents a running resistance to the hybrid vehicle, which is the sum of braking torques including a decelerating torque due to pumping losses of the engine when the hybrid vehicle is decelerating, a regenerative torque due to a regenerative resistance, a rolling resistance to the wheels of the hybrid vehicle, and an air resistance to the hybrid vehicle. The running resistance RUNRST is determined from a RUNRST table shown in FIG. 12. The RUNRST table is established such that the running resistance RUNRST is greater as the vehicle speed Vcar is higher, with the EGR control valve 121 being fully open.

[0052] The running status quantity VSTATUS determined by the vehicle speed Vcar and the extra output power POWERex corresponds to an assistive distribution ratio of the electric motor 3 with respect to the extra output power POWERex, and may be set to integral values (%) ranging from 0 to 200. If the running status quantity VSTATUS is

"0", then the hybrid vehicle is in a running status not to be assisted by the electric motor 3, i.e., the hybrid vehicle is decelerating or cruising. If the running status quantity VSTATUS is greater than "0", then the hybrid vehicle is in a running status to be assisted by the electric motor 3.

[0053] In STEP8, the energy distribution control unit 15 decides whether the running status quantity VSTATUS is greater than "0" or not. If VSTATUS > 0, i.e., if the hybrid vehicle is in a running status to be assisted by the electric motor 3, then the hybrid vehicle enters an assistive mode, and control goes from STEP8 to STEP9 shown in FIG. 6. If VSTATUS ≤ 0, i.e., if the hybrid vehicle is decelerating or cruising, then the hybrid vehicle enters a regenerative mode (i.e., a decelerating regenerative mode or a cruise charging mode), and control goes from STEP8 to STEP12 shown in FIG. 6.

[0054] In STEP9, the energy distribution control unit 15 calculates an electric motor output power POWERmot according to the following equation (3):

$$\mathrm{POWERmot} = \mathrm{POWERcom} \times \mathrm{PRATIO} \times \mathrm{PRATIOth} \times \mathrm{VSTATUS} \quad (3)$$

[0055] In STEP10, the energy distribution control unit 15 converts the electric motor output power POWERmot as a target with a time constant into an electric motor torque command TRQcom.

[0056] FIG. 13 shows the relationship between the electric motor output power POWERmot and the electric motor torque command TRQcom. In FIG. 13, the solid-line curve illustrates the electric motor output power POWERmot as it changes with time, and the dotted-line curve illustrates the electric motor torque command TRQcom as it changes with time.

[0057] As can be seen from FIG. 12, the electric motor torque command TRQcom is controlled so as to approach the electric motor output power POWERmot as a target with a time constant, i.e., with a time delay. If the electric motor torque command TRQcom were established such that the electric motor 3 would generate the electric motor output power POWERmot immediately in response to the electric motor torque command TRQcom, then since an increase in the output power of the engine 1 would be delayed, the engine 1 would not be readied to accept the electric motor output power POWERmot immediately, with the result that the drivability of the hybrid vehicle would be impaired. It is necessary, therefore, to control the electric motor 3 to generate the electric motor output power POWERmot until the engine 1 becomes ready to accept the electric motor output power POWERmot.

[0058] In STEP11, the energy distribution control unit 15 calculates a corrective quantity θthASSIST for controlling a target value θthO for the throttle valve opening in a valve closing direction, depending on the electric motor torque command TRQcom. Thereafter, control goes from STEP11 to STEP18.

[0059] The corrective quantity θthASSIST serves to reduce the output power of the engine 1 by an amount commensurate with the increase in the output power of the electric motor 3 responsive to the electric motor torque command TRQcom. The corrective quantity θthASSIST is calculated for the following reasons:

[0060] When the target value θthO for the throttle valve opening is determined by the corrective term θthADD calculated in STEP6 from the throttle valve opening command θthCOM determined in STEP3 and the previous throttle valve opening θthi, and the throttle actuator 105 is controlled by the target value θthO, the demand drive power POWERcom is generated solely from the output power of the engine 1. Therefore, if the output power of the engine 1 were controlled with the target value θthO not corrected by the corrective quantity θthASSIST, and the electric motor 3 were controlled by the electric motor torque command TRQcom converted in STEP10, the sum of the output power of the engine 1 and the output power of the electric motor 3 would exceed the demand drive power POWERcom, resulting in a drive power greater than the demand drive power demanded by the driver. To avoid this problem, the output power of the engine 1 is reduced by an amount commensurate with the output power of the electric motor 3, and the corrective quantity θthASSIST is calculated such that the sum of the output power of the engine 1 and the output power of the electric motor 3 will be equalized to the demand drive power POWERcom. The target value θthO for the throttle valve 103 is then determined (θthO = θthi + θthADD - θthASSIST), and the throttle valve 103 is controlled according to the target value θthO for suppressing the output power of the engine 1.

[0061] In STEP12, the energy distribution control unit 15 decides whether the present regenerative mode is the decelerating regenerative mode or the cruise charging mode. Specifically, the energy distribution control unit 15 makes such a mode decision by deciding whether a change Dap (= θapj (present value) - θapi (previous value) in the accelerator opening θap is smaller than a predetermined negative quantity DapD. Alternatively, the energy distribution control unit 15 may make such a mode decision based on the extra output power POWERex.

[0062] If Dap < DapD or POWERex < 0 in STEP12, then the energy distribution control unit 15 judges the present regenerative mode as the decelerating regenerative mode, and sets the electric motor output power POWERmot to a decelerating regenerative output power POWERreg in STEP13. The decelerating regenerative output power POW-

ERreg is calculated according to a decelerating regenerative processing routine which will be described later on with reference to FIGS. 15 and 16.

[0063] In STEP14, the energy distribution control unit 15 reads an optimum target value θthO for the throttle valve opening in the decelerating regenerative mode, i.e., an optimum target value θthO for the throttle valve opening calculated in the decelerating regenerative processing routine (FIGS. 15 and 16). Thereafter, control proceeds to STEP19.

[0064] If Dap ≥ DapD or POWERex is nearly zero and VSTATUS = 0 in STEP12, then the energy distribution control unit 15 judges the present regenerative mode as the cruise charging mode, and sets the electric motor output power POWERmot to a cruise charging output power POWERcrui in STEP15. The cruise charging output power POWERcrui is calculated according to a cruise charging processing routine (not shown).

[0065] In STEP16, the energy distribution control unit 15 converts the electric motor output power POWERmot as a target with a time constant into an electric motor torque command TRQcom. In STEP 17, the energy distribution control unit 15 calculates a corrective quantity θthSUB for controlling a target value θthO for the throttle valve opening in a valve opening direction, depending on the electric motor torque command TRQcom. Thereafter, control goes from STEP17 to STEP18.

[0066] The corrective quantity θthSUB is calculated for the reasons that are opposite to the reasons for which the corrective quantity θthASSIST is calculated as described above.

[0067] The electric motor output power POWERmot in the cruise charging mode has a sign opposite to the sign of the electric motor output power POWERmot in the assistive mode. Specifically, in the cruise charging mode, the electric motor 3 is controlled in a direction to reduce the demand drive power POWERcom because of the electric motor torque command TRQcom which is negative. In order to maintain the demand drive power POWERcom in the cruise charging mode, it is necessary to make up for the output power of the electric motor 3 reduced by the electric motor torque command TRQcom, with the output power of the engine 1.

[0068] In STEP18, the energy distribution control unit 15 calculates the target value θthO for the throttle valve 103 according to the following equation (4):

$$\theta thO = \theta thi + \theta thADD - \theta thSUB \tag{4}$$

[0069] In STEP19, the energy distribution control unit 15 decides whether or not the calculated target value θthO is equal to or greater than a predetermined reference value θthREF. If θthO < θthREF, the energy distribution control unit 15 decides whether or not an intake pipe absolute pressure Pba is equal to or smaller than a predetermined reference value PbaREF in STEP20.

[0070] If Pba > PbaREF, then the processing sequence shown in FIGS. 5 and 6 is finished. If θthO ≥ θthREF in STEP19 or if Pba ≤ PbaREF in STEP20, then the energy distribution control unit 15 changes the speed reduction ratio of the transmission mechanism 4 to a lower speed reduction ratio in STEP21. Thereafter, the processing sequence shown in FIGS. 5 and 6 is finished.

[0071] When control goes to STEP21, the remaining capacity of the ultracapacitor 14 is reduced thereby to reduce the electric motor output power POWERmot, and the reduction in the electric motor output power POWERmot needs to be made up for by the engine 1, but the output power of the engine 1 cannot be increased anymore. At this time, the speed reduction ratio of the transmission mechanism 4 is changed to a lower speed reduction ratio to keep the torque produced by the drive axle 2 at a constant level, i.e., the same torque as before STEP21, to keep desired drivability of the hybrid vehicle.

[0072] An engine control process carried out by the engine control unit 11 will be described below.

[0073] FIG. 14 shows an overall engine control processing sequence, which is executed by the engine control unit 11 in each periodic cycle.

[0074] In FIG. 14, the engine control unit 11 detects various engine operating parameters including the engine rotational speed NE, the intake pipe absolute pressure Pba. etc. in STEP131. Then, the engine control unit 11 determines an engine operating status in STEP132, controls fuel to be supplied to the engine 1 in STEP133, and controls ignition timing of the engine 1 in STEP134.

[0075] In STEP 133, the engine control unit 11 calculates an amount of fuel to be supplied to the engine 1 depending on the read or calculated target value θthO for the throttle valve opening.

[0076] FIGS. 15 and 16 show a processing sequence for determining a decelerating regenerative quantity according to a first embodiment of the present invention. The processing sequence shown in FIGS. 15 and 16 is executed by the electric motor control unit 12 at each periodic interval.

[0077] As shown in FIG. 15, the electric motor control unit 12 decides whether a condition for a fuel cut is satisfied or not in STEP1501. If a condition for a fuel cut is satisfied, then the electric motor control unit 12 decides whether a condition for forced return from a fuel cut is satisfied or not in STEP1502. If a condition for forced return from a fuel cut is not satisfied, then the electric motor control unit 12 decides whether a condition for return from a fuel cut is

satisfied or not in STEP1503.

[0078] These conditions are determined by the change Dap in the accelerator opening θap in the determination of the engine operating status in STEP132 (see FIG. 14). For example, if Dap < DapD (a given negative quantity), then a condition for a fuel cut is satisfied. If Dap > DapH (a given positive quantity greater than DapD), then a condition for forced return from a fuel cut is satisfied. If Dap ≥ DapD, a condition for return from a fuel cut is satisfied.

[0079] If a condition for return from a fuel cut is not satisfied in STEP1503, the electric motor control unit 12 determines a running resistance RUNRST from the RUNRST table shown in FIG. 12 in STEP1504, and then determines a desired running resistance RUNRSTcom from the RUNRSTcom table in STEP1505. The desired running resistance RUNRSTcom is a braking torque for applying a suitable negative acceleration to the hybrid vehicle. As shown in FIG. 17, the RUNRSTcom table is established such that the desired running resistance RUNRSTcom is greater as the vehicle speed Vcar or the rotational speed of the drive axle 2 is higher.

[0080] Then, the electric motor control unit 12 calculates a decelerating regenerative quantity REGdec according to the following equation (5) in STEP1506:

$$\mathrm{REGdec} = \mathrm{RUNRSTcom} - \mathrm{RUNRST} \quad (5)$$

[0081] Thereafter, the electric motor control unit 12 determines a first allowable regenerative quantity REGperml from a REGperml table in STEP1507. As shown in FIG. 18, the REGperml table is established such that the first allowable regenerative quantity REGperml is constant when the remaining capacity CAPrem of the ultracapacitor 14 is smaller than a predetermined value, and becomes smaller as the remaining capacity CAPrem is greater when the remaining capacity CAPrem is greater than the predetermined value.

[0082] The electric motor control unit 12 then determines a second allowable regenerative quantity REGperm2 from a REGperm2 table in STEP1508. As shown in FIG. 19, the REGperm2 table is established such that the second allowable regenerative quantity REGperm2 is constant when the circuit temperature (protective resistor temperature) TD of the power drive unit 13 is smaller than a predetermined value, and becomes smaller as the protective resistor temperature TD is greater when the protective resistor temperature TD is greater than the predetermined value.

[0083] Then, the electric motor control unit 12 decides whether or not the first allowable regenerative quantity REGperml is equal to or greater than the second allowable regenerative quantity REGperm2 in STEP1509. If REGperml < REGperm2, then the electric motor control unit 12 sets a allowable regenerative quantity REGperm to the first allowable regenerative quantity REGperml in STEP1510, after which control goes to STEP2212 shown in FIG. 16. If REGperml ≥ REGperm2, then the electric motor control unit 12 sets the allowable regenerative quantity REGperm to the second allowable regenerative quantity REGperm2 in STEP1511, after which control goes to STEP2212 shown in FIG. 16.

[0084] If the remaining capacity CAPrem of the ultracapacitor 14 or the temperature TD of the protective resistor of the drive circuit for the electric motor 3 is in excess of a predetermined threshold value, the allowable regenerative quantity REGperm may be set to "0" rather than determining the first and second allowable regenerative quantities REGperml, REGperm2 from the respective tables.

[0085] In STEP2212, the electric motor control unit 12 decides whether or not the allowable regenerative quantity REGperm is equal to or greater than the decelerating regenerative quantity REGdec. If REGperm ≥ REGdec, then the electric motor control unit 12 sets the target opening θthO for the throttle valve 103 to "0" (substantially fully closed) in STEP2213, and outputs a command to fully open the EGR control valve 121, which serves as a pumping loss control means in this embodiment, in STEP2214. In this manner, the pumping losses of the engine 1 can be reduced.

[0086] Specifically, as shown in FIG. 20, the EGR control valve 121 is fully opened to reduce a pressure reduction in the intake system and introduce high-temperature recirculating gases into the intake pipe. Therefore, the pumping losses of the engine 1 are reduced, and the three-way catalytic converter 115 is prevented from suffering a drop in its temperature.

[0087] Referring back to FIG. 16, the electric motor control unit 12 sets the decelerating regenerative output power POWERreg to the decelerating regenerative quantity REGdec in STEP2215, sets a countdown timer tmF/C to a predetermined time TmF/C and starts the countdown timer tmF/C in STEP2221. Thereafter, the processing sequence shown in FIGS. 15 and 16 is finished. The predetermined time TmF/C is selected to be a period of time long enough for the recirculation ratio of the exhaust gases to become normal after the EGR control valve 121 has started its normal control operation.

[0088] If REGperm < REGdec in STEP2212, the electric motor control unit 12 sets the target opening θthO for the throttle valve 103 to "0" (substantially fully closed) in STEP2216, and then calculates a regeneration limiting quantity REGlim according to the following equation (6) in STEP2217:

$$\mathrm{REGlim} = \mathrm{REGdec} - \mathrm{REGperm} \quad (6)$$

[0089] Then, the electric motor control unit 12 calculates a target valve opening θEGRO for the EGR control valve 121 as a corrective value for the decelerating resistance (deceleration) in STEP2218. The target valve opening θEGRO is calculated from a θEGRO map which uses the regeneration limiting quantity REGlim and the vehicle speed Vcar as parameters. The θEGRO map is established such that the target valve opening θEGRO is smaller as the regeneration limiting quantity REGlim and the vehicle speed Vcar are greater. Then, the electric motor control unit 12 outputs a command to control the EGR control valve 121 to reach the target valve opening θEGRO for thereby correcting the decelerating resistance in STEP2219. When the regenerating operation of the electric motor 3 is limited, therefore, the pumping losses of the engine 1 are appropriately increased and the braking torques are not varied, eliminating an uncomfortable feeling which the driver would otherwise have when the hybrid vehicle is decelerated.

[0090] Then, the electric motor control unit 12 sets the decelerating regenerative output power POWERreg to decelerating regenerative quantity REGdec in STEP2220. Thereafter, the electric motor control unit 12 executes STEP2221, and then the processing sequence shown in FIGS. 15 and 16 is finished.

[0091] If a condition for a fuel cut is not satisfied in STEP1501, or if a condition for forced return from a fuel cut is satisfied in STEP1502, then the electric motor control unit 12 carries out ordinary control of the EGR control valve 121 in STEP2224, and effects return from a fuel cut in STEP2225. Thereafter, the processing sequence shown in FIGS. 15 and 16 is finished.

[0092] If a condition for return from a fuel cut is satisfied in STEP1503, then the electric motor control unit 12 decides whether the countdown timer tmF/C has reached "0" or not in STEP2222. If the countdown timer tmF/C has not yet reached "0", then the electric motor control unit 12 carries out ordinary control of the EGR control valve 121 in STEP2223, after which the processing sequence shown in FIGS. 15 and 16 is finished. If the countdown timer tmF/C has reached "0" in STEP2222, then control jumps from STEP2222 to STEP2224.

[0093] According to the first embodiment, if the regenerating operation of the electric motor 3 is not limited while the hybrid vehicle is decelerating, the EGR control valve 121 is operated in an opening direction to a substantially fully open position in STEP2214. Therefore, since the recirculating gases smoothly circulate into the engine 1, the pumping losses of the engine 1 can be lowered, and the regenerative efficiency can be increased.

[0094] At the same time, the throttle valve 103 is operated in a closing direction to a substantially fully closed position in STEP2213. Therefore, the amount of any cold fresh air flowing through the throttle valve 103 in response to operation of the engine 1 is small. Since high-temperature exhaust gasses are recirculated, the temperature of the three-way catalytic converter 115 is prevented from falling, and hence the emission characteristics thereof are prevented from being impaired.

[0095] If the regenerating operation of the electric motor 3 is limited, the EGR control valve 121 is operated in a more closing direction than if the regenerating operation of the electric motor 3 is not limited, and the target valve opening θEGRO is established depending on the regeneration limiting quantity REGlim in STEP2217 - STEP2219. Consequently, the pumping losses increase depending on a reduction in the regenerative torque, so that the braking torques will not vary. Therefore, the drivability of the hybrid vehicle due to the limited regenerating operation is prevented from being impaired. For example, an uncomfortable feeling which the driver may have due to a change in the deceleration of the hybrid vehicle is reduced.

[0096] A second embodiment of the present invention will be described below. In the second embodiment, each of the intake valves 122 or the exhaust valves 123 is used as a pumping loss control means. Therefore, the second embodiment differs from the first embodiment as to the process of determining a decelerating regenerative quantity. System details, control unit details, and other details of the processing sequence according to the second embodiment are identical to those of the first embodiment.

[0097] FIGS. 15 and 21 show a processing sequence for determining a decelerating regenerative quantity according to the second embodiment of the present invention. The processing of STEP1501 - STEP1511 shown in FIG. 15 according to the second embodiment is the same as the processing of STEP1501 - STEP1511 described above.

[0098] In STEP2512 shown in FIG. 21, the electric motor control unit 12 decides whether or not the allowable regenerative quantity REGperm is equal to or greater than the decelerating regenerative quantity REGdec. If REGperm ≥ REGdec, then the electric motor control unit 12 sets the target opening θthO for the throttle valve 103 to "0" (substantially fully closed) in STEP2513, and outputs a command to fully open the intake valve 122 in STEP2514. Since the intake valve 122 is kept open as shown in FIG. 22, the pumping losses are fully lowered, and cold fresh air is prevented from flowing into the exhaust system, so that the three-way catalytic converter 115 will not be excessively cooled.

[0099] Referring back to FIG. 21, the electric motor control unit 12 sets the decelerating regenerative output power POWERreg to the decelerating regenerative quantity REGdec in STEP2515, sets a countdown timer tmF/C to a predetermined time TmF/C and starts the countdown timer tmF/C in STEP2521. Thereafter, the processing sequence shown in FIGS. 15 and 21 is finished. The predetermined time TmF/C is selected to be a period of time long enough for a suitable amount of fresh air to be maintained after the intake valve 122 has started its normal control operation.

[0100] If REGperm < REGdec in STEP2512, the electric motor control unit 12 sets the target opening θthO for the

throttle valve 103 to "0" (substantially fully closed) in STEP2516, and then calculates a regeneration limiting quantity REGlim according to the above equation (6) in STEP2517.

[0101] Then, the electric motor control unit 12 calculates a target valve lift LIFTin and a valve opening period Tin for the intake valve 122 as a corrective value for the decelerating resistance (deceleration) in STEP2518. The target valve lift LIFTin and the valve opening period Tin are calculated from a LIFTin map which uses the regeneration limiting quantity REGlim and the vehicle speed Vcar as parameters. The LIFTin map is established such that in most areas, the target valve lift LIFTin and the valve opening period Tin are greater as the regeneration limiting quantity REGlim is smaller and the vehicle speed Vcar is higher.

[0102] The electric motor control unit 12 outputs a command to control the intake valve 122 to reach the target valve lift LIFTin and the valve opening period Tin for thereby correcting the decelerating resistance in STEP2519. When the regenerating operation of the electric motor 3 is limited, therefore, the pumping losses of the engine 1 are increased depending on a reduction in the regenerative torque and the braking torques are not varied when the hybrid vehicle is decelerated, preventing the drivability of the hybrid vehicle from being impaired.

[0103] Then, the electric motor control unit 12 sets the decelerating regenerative output power POWERreg to decelerating regenerative quantity REGdec in STEP2520. Thereafter, the electric motor control unit 12 executes STEP2521, and then the processing sequence shown in FIGS. 15 and 21 is finished.

[0104] The same advantages are obtained if the electric motor control unit 12 outputs a command to fully open the exhaust valve 123 in STEP2514. In this case, the electric motor control unit 12 determines a target valve lift LIFTex or a valve opening period Tex for the exhaust valve 123 from a map, and controls the exhaust valve 123 to reach the target valve lift LIFTex or the valve opening period Tex for thereby correcting the decelerating resistance.

[0105] If a condition for a fuel cut is not satisfied in STEP1501, or if a condition for forced return from a fuel cut is satisfied in STEP1502, then the electric motor control unit 12 carries out ordinary control of the intake valve 122 in STEP2524, and effects return from a fuel cut in STEP2525. Thereafter, the processing sequence shown in FIGS. 15 and 21 is finished.

[0106] If a condition for return from a fuel cut is satisfied in STEP1503, then the electric motor control unit 12 decides whether the countdown timer tmF/C has reached "0" or not in STEP2522. If the countdown timer tmF/C has not yet reached "0", then the electric motor control unit 12 carries out ordinary control of the intake valve 122 in STEP2523, after which the processing sequence shown in FIGS. 15 and 21 is finished. If the countdown timer tmF/C has reached "0" in STEP2522, then control jumps from STEP2522 to STEP2524.

[0107] According to the second embodiment, if the regenerating operation of the electric motor 3 is not limited while the hybrid vehicle is decelerating, the intake valve 122 or the exhaust valve 123 is kept a substantially fully open position in STEP2514. Therefore, the pumping losses of the engine 1 are lowered, and cold fresh air introduced by the operation of the engine 1 is prevented from flowing into the exhaust system. Thus, the temperature of the three-way catalytic converter 115 is prevented from falling, and hence the regenerative efficiency is increased and the emission characteristics are prevented from being impaired.

[0108] If the regenerating operation of the electric motor 3 is limited, the intake valve 122 or the exhaust valve 123 is operated in a more closing direction than if the regenerating operation of the electric motor 3 is not limited, and the target valve lift and the valve opening period are established depending on the regeneration limiting quantity REGlim in STEP2517 - STEP2519. Consequently, the pumping losses increase depending on a reduction in the regenerative torque due to the limited regenerating operation, so that the braking torques will not vary. Therefore, the drivability of the hybrid vehicle is prevented from being impaired.

[0109] A third embodiment of the present invention will be described below. In the third embodiment, each of the intake valves 122 and each of the exhaust valves 123 are used as a pumping loss control means. Therefore, the third embodiment differs from the first embodiment as to the process of determining a decelerating regenerative quantity. System details, control unit details, and other details of the processing sequence according to the third embodiment are identical to those of the first embodiment.

[0110] FIGS. 15 and 23 show a processing sequence for determining a decelerating regenerative quantity according to the third embodiment of the present invention. The processing of STEP1501 - STEP1511 shown in FIG. 15 according to the third embodiment is the same as the processing of STEP1501 - STEP1511 described above.

[0111] In STEP3112 shown in FIG. 21, the electric motor control unit 12 decides whether or not the allowable regenerative quantity REGperm is equal to or greater than the decelerating regenerative quantity REGdec. If REGperm ≥ REGdec, then the electric motor control unit 12 sets the target opening θthO for the throttle valve 103 to "0" (substantially fully closed) in STEP3113, and outputs a command to fully close the intake and exhaust valves 122, 123 in STEP3114. Since the intake and exhaust valves 122, 123 are kept closed as shown in FIG. 24, the pumping losses of the engine 1 are lowered, and cold fresh air is prevented from flowing into the three-way catalytic converter 115, which will not be excessively cooled.

[0112] Referring back to FIG. 23, the electric motor control unit 12 sets the decelerating regenerative output power POWERreg to the decelerating regenerative quantity REGdec in STEP3115, sets a countdown timer tmF/C to a pre-

determined time TmF/C and starts the countdown timer tmF/C in STEP3121. Thereafter, the processing sequence shown in FIGS. 15 and 23 is finished. The predetermined time TmF/C is selected to be a period of time long enough for a suitable amount of fresh air to be maintained after the intake and exhaust valves 122, 123 have started its normal control operation.

[0113] If REGperm < REGdec in STEP3112, the electric motor control unit 12 sets the target opening θthO for the throttle valve 103 to "0" (substantially fully closed) in STEP3116, and then calculates a regeneration limiting quantity REGlim according to the above equation (6) in STEP3117.

[0114] Then, the electric motor control unit 12 calculates a target valve lift LIFTin and a valve opening period Tin for the intake valve 122 and a target valve lift LIFTex or a valve opening period Tex for the exhaust valve 123 as a corrective value for the decelerating resistance (deceleration) in STEP3118. The target valve lift LIFTin and the valve opening period Tin and the target valve lift LIFTex and the valve opening period Tex are calculated from a LIFTin·LIFTex map which uses the regeneration limiting quantity REGlim and the vehicle speed Vcar as parameters. The LIFTin·LIFTex map is established such that in most areas, the target valve lift LIFTin and the valve opening period Tin and the target valve lift LIFTex and the valve opening period Tex are greater as the regeneration limiting quantity REGlim is smaller and the vehicle speed Vcar is higher. The pumping losses of the engine 1 are minimum when the intake and exhaust valves 122, 123 are fully closed, and maximum when the intake and exhaust valves 122, 123 are slightly opened to a given open position. When the intake and exhaust valves 122, 123 are further opened from the given open position, the pumping losses of the engine 1 are gradually reduced. Therefore, the LIFTin·LIFTex map is established with respect to the target valve lift LIFTin and the valve opening period Tin and the target valve lift LIFTex and the valve opening period Tex in view of the above behaviors of the pumping losses.

[0115] The electric motor control unit 12 outputs a command to control the intake valve 122 to reach the target valve lift LIFTin and the valve opening period Tin and a command to control the exhaust valve 123 to reach the target valve lift LIFTex and the valve opening period Tex for thereby correcting the decelerating resistance in STEP3119. When the regenerating operation of the electric motor 3 is limited, therefore, the pumping losses of the engine 1 are appropriately increased depending on a reduction in the regenerative torque and the braking torques are not varied. The decelerating resistance may be corrected by at least one of the target valve lifts LIFTin, LIFTex and the valve opening periods Tin, Tex.

[0116] Then, the electric motor control unit 12 sets the decelerating regenerative output power POWERreg to decelerating regenerative quantity REGdec in STEP3120. Thereafter, the electric motor control unit 12 executes STEP3121, and then the processing sequence shown in FIGS. 15 and 23 is finished.

[0117] If a condition for a fuel cut is not satisfied in STEP 1501, or if a condition for forced return from a fuel cut is satisfied in STEP1502, then the electric motor control unit 12 carries out ordinary control of the intake and exhaust valves 122, 123 in STEP3124, and effects return from a fuel cut in STEP3125. Thereafter, the processing sequence shown in FIGS. 15 and 23 is finished.

[0118] If a condition for return from a fuel cut is satisfied in STEP1503, then the electric motor control unit 12 decides whether the countdown timer tmF/C has reached "0" or not in STEP3122. If the countdown timer tmF/C has not yet reached "0", then the electric motor control unit 12 carries out ordinary control of the intake and exhaust valves 122, 123 in STEP3123, after which the processing sequence shown in FIGS. 15 and 21 is finished. If the countdown timer tmF/C has reached "0" in STEP3122, then control jumps from STEP3122 to STEP3124.

[0119] According to the third embodiment, if the regenerating operation of the electric motor 3 is not limited while the hybrid vehicle is decelerating, the intake and exhaust valves 122, 123 are operated in a closing direction to a substantially fully closed position in STEP3114. Therefore, since almost no gasses flow into and out of the combustion chambers, the pumping losses of the engine 1 are lowered, and cold fresh air is prevented from flowing into the three-way catalytic converter 115. Thus, the temperature of the three-way catalytic converter 115 is prevented from falling, and hence the regenerative efficiency is increased and the emission characteristics are prevented from being impaired.

[0120] If the regenerating operation of the electric motor 3 is limited, the intake and exhaust valves 122, 123 are operated in a more opening direction than if the regenerating operation of the electric motor 3 is not limited, and the target valve lifts LIFTin, LIFTex and the valve opening periods Tin, Tex are established depending on the regeneration limiting quantity REGlim in STEP3117 - STEP3119. Consequently, the pumping losses increase depending on a reduction in the regenerative torque due to the limited regenerating operation, so that the braking torques will not vary. Therefore, the drivability of the hybrid vehicle is prevented from being impaired.

[0121] Rather than employing the intake valve actuators 125 and the exhaust valve actuators 126 to operate the intake and exhaust valves 122, 123, the control system according to the present invention may have a known valve actuating device for varying valve lifts and valve opening and closing periods for the intake and exhaust valves 122, 123, the valve actuating device being capable of disabling selected ones of the intake and exhaust valves 122, 123.

[0122] The throttle valve 103 whose opening is controlled by the electrically operated actuator 105 may be replaced with an ordinary throttle valve that is mechanically linked to the accelerator pedal. In such a modification, the amount of intake air depending on the output power of the electric motor may be controlled by a passage bypassing the throttle

valve and a control valve disposed in the passage.

[0123] In the third embodiment in which the intake and exhaust valves are used as the pumping loss control means, the valve lifts and the valve opening periods of the intake and exhaust valves are continuously varied. However, the valve lifts and the valve opening periods of the intake and exhaust valves may be varied stepwise only when the corrective value for the deceleration resistance exceeds a certain threshold value.

[0124] While the ultracapacitor is employed as the electric energy storage unit in the illustrated embodiments, the electric energy storage unit may instead comprise a battery.

[0125] Although certain preferred embodiments of the present invention have been shown and described in detail, it should be understood that various changes and modifications may be made therein without departing from the scope of the appended claims.

Claims

1. A control system for controlling a hybrid vehicle having an engine for rotating a drive axle, an electric motor for converting kinetic energy of the drive axle into electric energy in a regenerative mode, a drive control circuit for controlling the electric motor, and electric energy storage means for storing electric energy, comprising:

    intake air control means for controlling an amount of intake air supplied to the engine;
    an exhaust gas recirculation control valve for controlling recirculation of exhaust gases from an exhaust system of the engine to an intake system of the engine; and
    control means for operating said intake air control means to reduce said amount of intake air and operating said exhaust gas recirculation control valve in an opening direction when the electric motor operates in the regenerative mode while the hybrid vehicle is decelerating.

2. A control system according to claim 1, further comprising:

    regenerative quantity establishing means for establishing a regenerative quantity depending on a vehicle speed of the hybrid vehicle when the hybrid vehicle is decelerating; and
    regeneration limiting quantity establishing means for establishing a regeneration limiting quantity to limit the regenerative quantity depending on a remaining capacity of the electric energy storage means;
    said control means comprising means for operating said exhaust gas recirculation control valve in a closing direction based on the regeneration limiting quantity established by said regeneration limiting quantity establishing means.

3. A control system for controlling a hybrid vehicle having an engine for rotating a drive axle, an electric motor for converting kinetic energy of the drive axle into electric energy in a regenerative mode, a drive control circuit for controlling the electric motor, and electric energy storage means for storing electric energy, comprising:

    intake air control means for controlling an amount of intake air supplied to the engine;
    intake valve actuating means for actuating an intake valve of the engine; and
    control means for operating said intake air control means to reduce said amount of intake air and controlling said intake valve actuating means to operate said intake valve in an opening direction when the electric motor operates in the regenerative mode while the hybrid vehicle is decelerating.

4. A control system according to claim 3, further comprising:

    regenerative quantity establishing means for establishing a regenerative quantity depending on a vehicle speed of the hybrid vehicle when the hybrid vehicle is decelerating; and
    regeneration limiting quantity establishing means for establishing a regeneration limiting quantity to limit the regenerative quantity depending on a remaining capacity of the electric energy storage means;
    said control means comprising means for controlling said intake valve actuating means based on a valve lift or a valve opening period established based on the regeneration limiting quantity established by said regeneration limiting quantity establishing means.

5. A control system for controlling a hybrid vehicle having an engine for rotating a drive axle, an electric motor for converting kinetic energy of the drive axle into electric energy in a regenerative mode, a drive control circuit for controlling the electric motor, and electric energy storage means for storing electric energy, comprising:

intake air control means for controlling an amount of intake air supplied to the engine;
exhaust valve actuating means for actuating an exhaust valve of the engine; and
control means for operating said intake air control means to reduce said amount of intake air and controlling said exhaust valve actuating means to operate said exhaust valve in an opening direction when the electric motor operates in the regenerative mode while the hybrid vehicle is decelerating.

6. A control system for controlling a hybrid vehicle having an engine for rotating a drive axle and an electric motor for converting kinetic energy of the drive axle into electric energy in a regenerative mode, comprising:

intake valve actuating means for actuating an intake valve of the engine;
exhaust valve actuating means for actuating an exhaust valve of the engine; and
control means for operating said intake valve actuating means and said exhaust valve actuating means to operate said intake valve and said exhaust valve in a closing direction when the electric motor operates in the regenerative mode while the hybrid vehicle is decelerating.

7. A control system according to claim 5, further comprising:

regenerative quantity establishing means for establishing a regenerative quantity depending on a vehicle speed of the hybrid vehicle when the hybrid vehicle is decelerating; and
regeneration limiting quantity establishing means for establishing a regeneration limiting quantity to limit the regenerative quantity depending on a remaining capacity of the electric energy storage means;
said control means comprising means for controlling said intake valve actuating means or said exhaust valve actuating means based on a valve lift or a valve opening period established based on the regeneration limiting quantity established by said regeneration limiting quantity establishing means.

FIG. 1

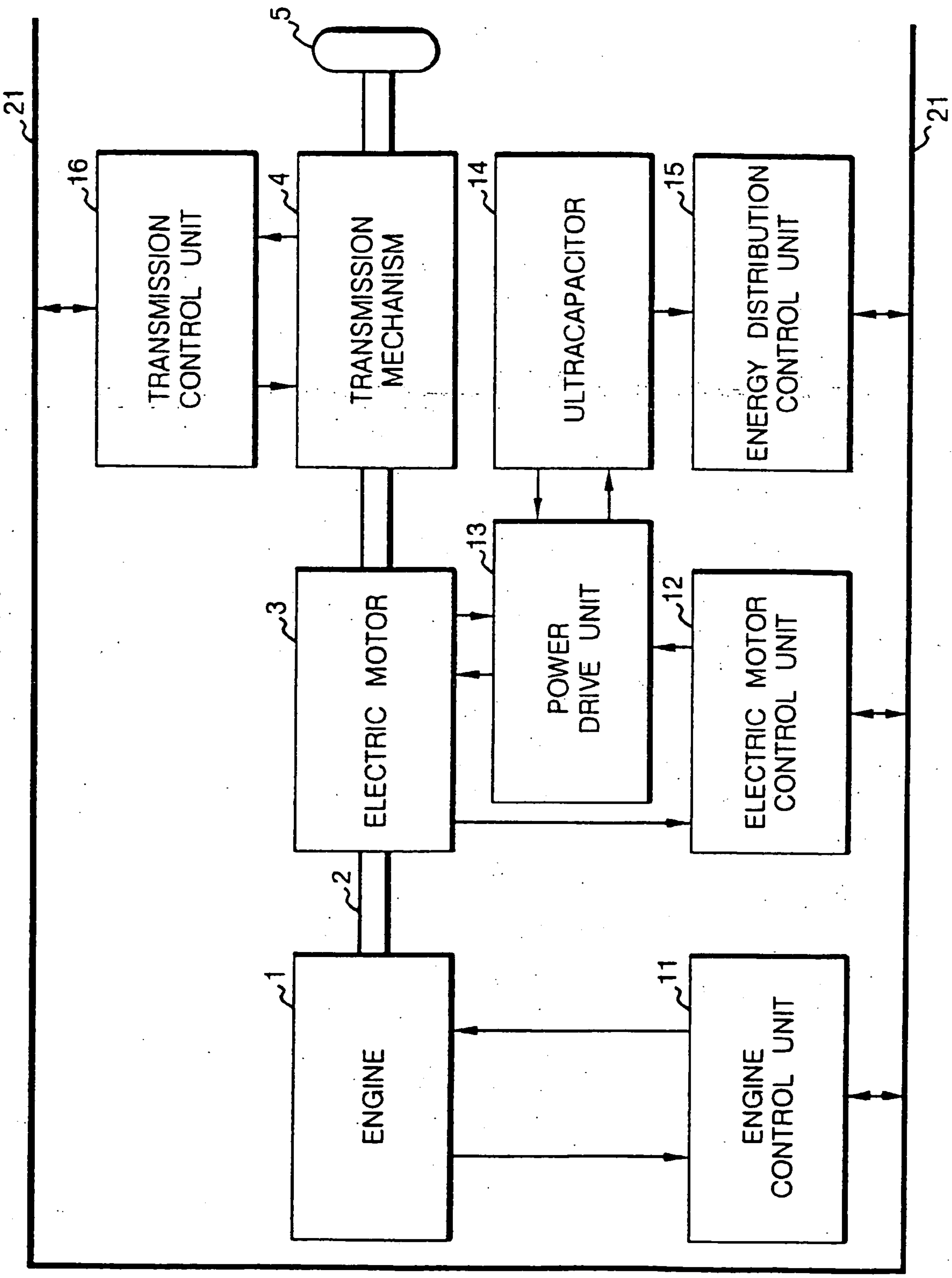

TRANSMISSION CONTROL UNIT
TRANSMISSION MECHANISM
ULTRACAPACITOR
ENERGY DISTRIBUTION CONTROL UNIT
ELECTRIC MOTOR
POWER DRIVE UNIT
ELECTRIC MOTOR CONTROL UNIT
ENGINE
ENGINE CONTROL UNIT
1
2
3
4
5
11
12
13
14
15
16
21
21

FIG. 2

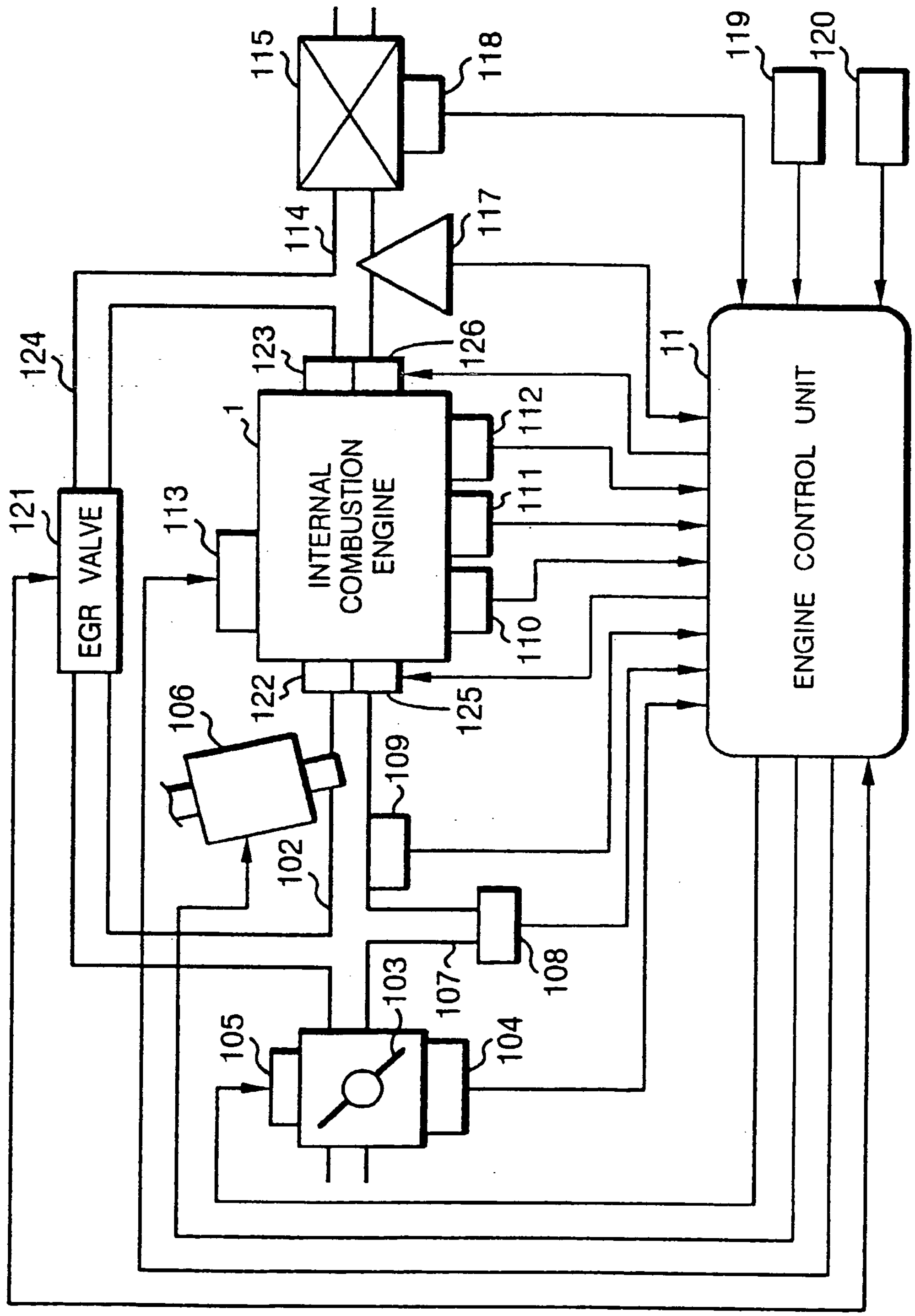

INTERNAL COMBUSTION ENGINE
EGR VALVE
ENGINE CONTROL UNIT
1
11
102
103
104
105
106
107
108
109
110
111
112
113
114
115
117
118
119
120
121
122
123
124
125
126

FIG. 3

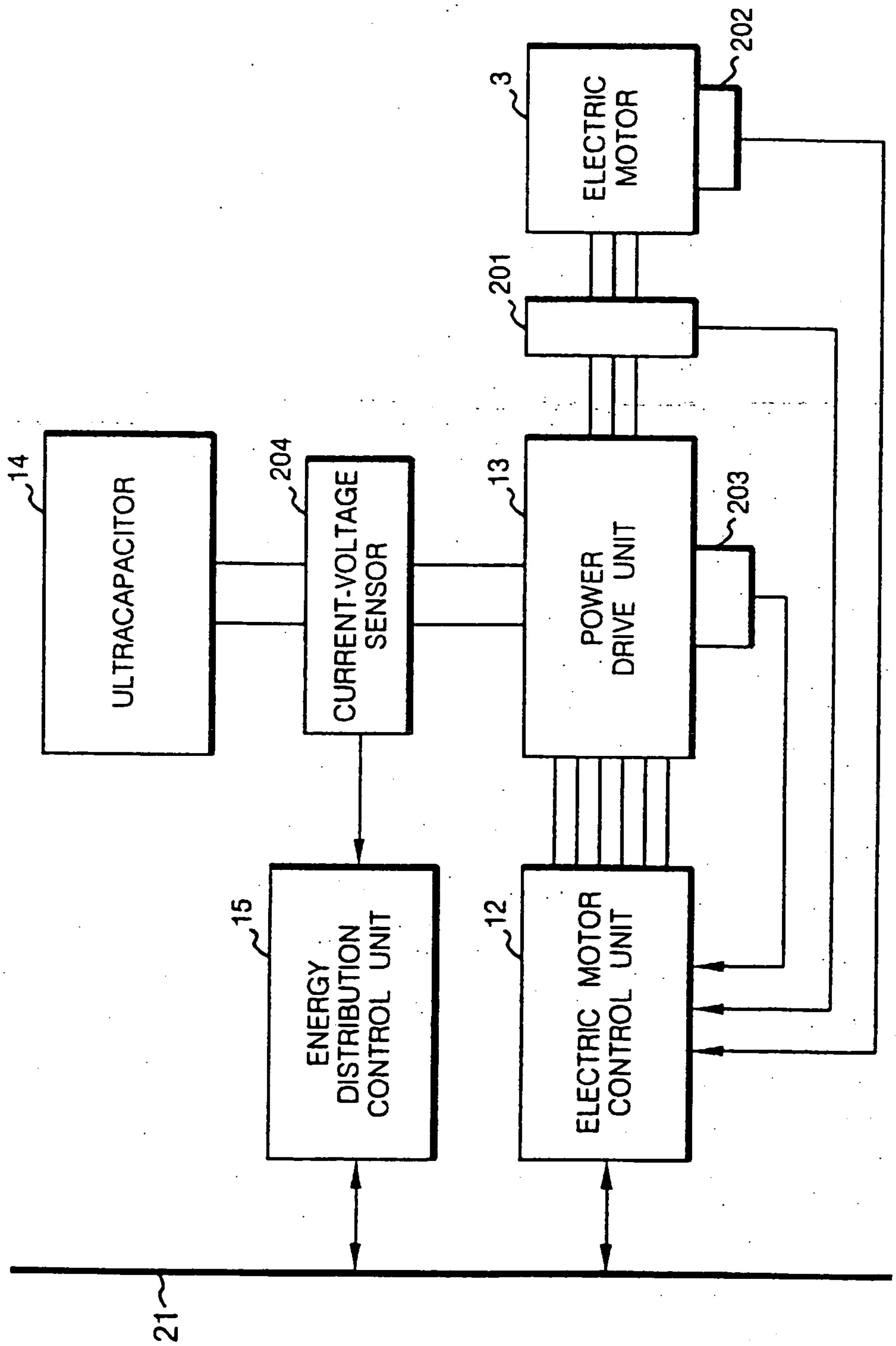

ULTRACAPACITOR
14
CURRENT-VOLTAGE SENSOR
204
POWER DRIVE UNIT
13
203
201
ELECTRIC MOTOR
3
202
ENERGY DISTRIBUTION CONTROL UNIT
15
ELECTRIC MOTOR CONTROL UNIT
12
21

FIG. 4

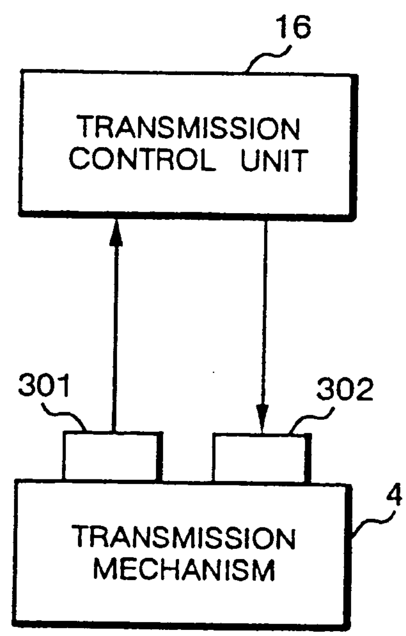

16
TRANSMISSION CONTROL UNIT
301
302
4
TRANSMISSION MECHANISM

FIG. 5

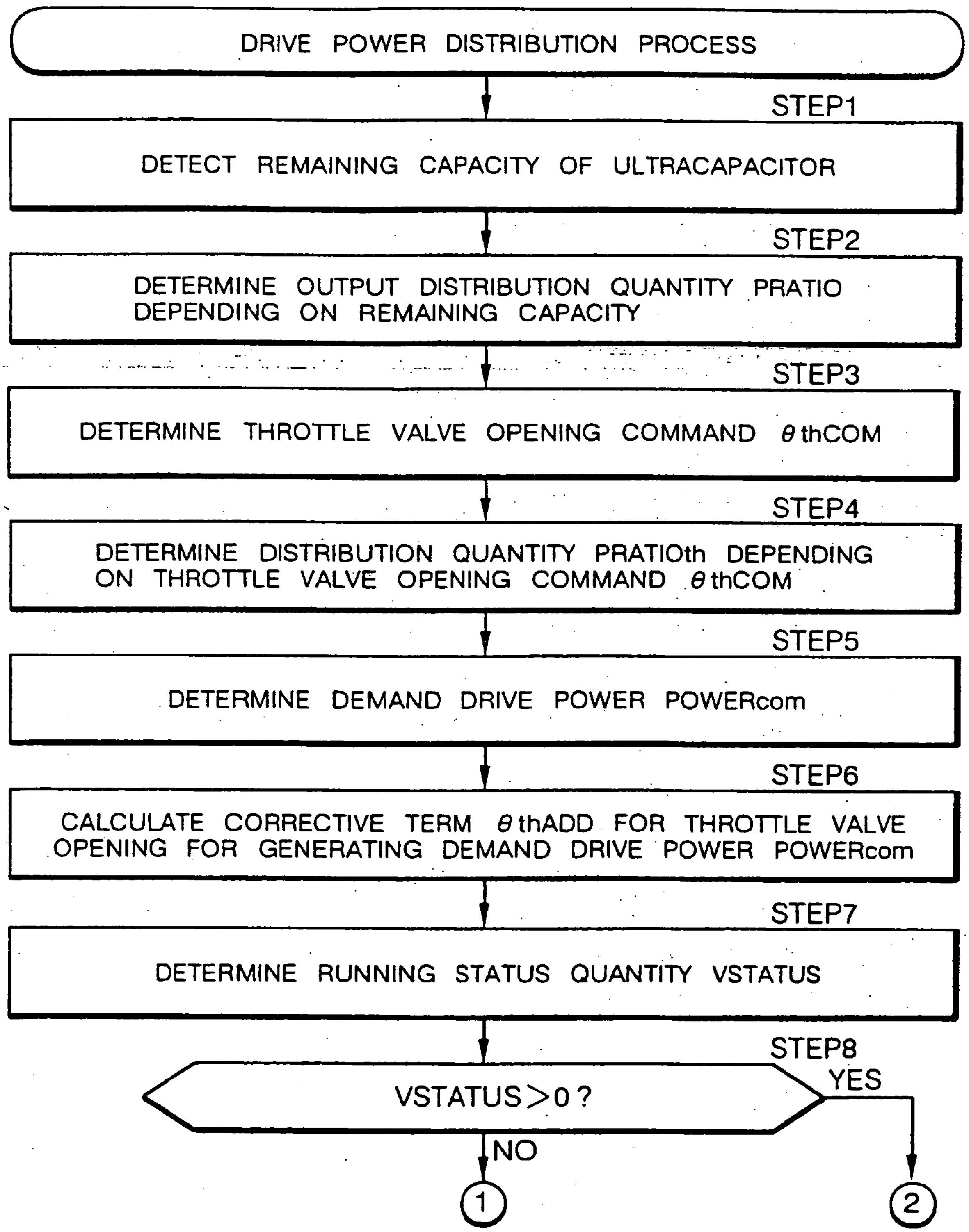
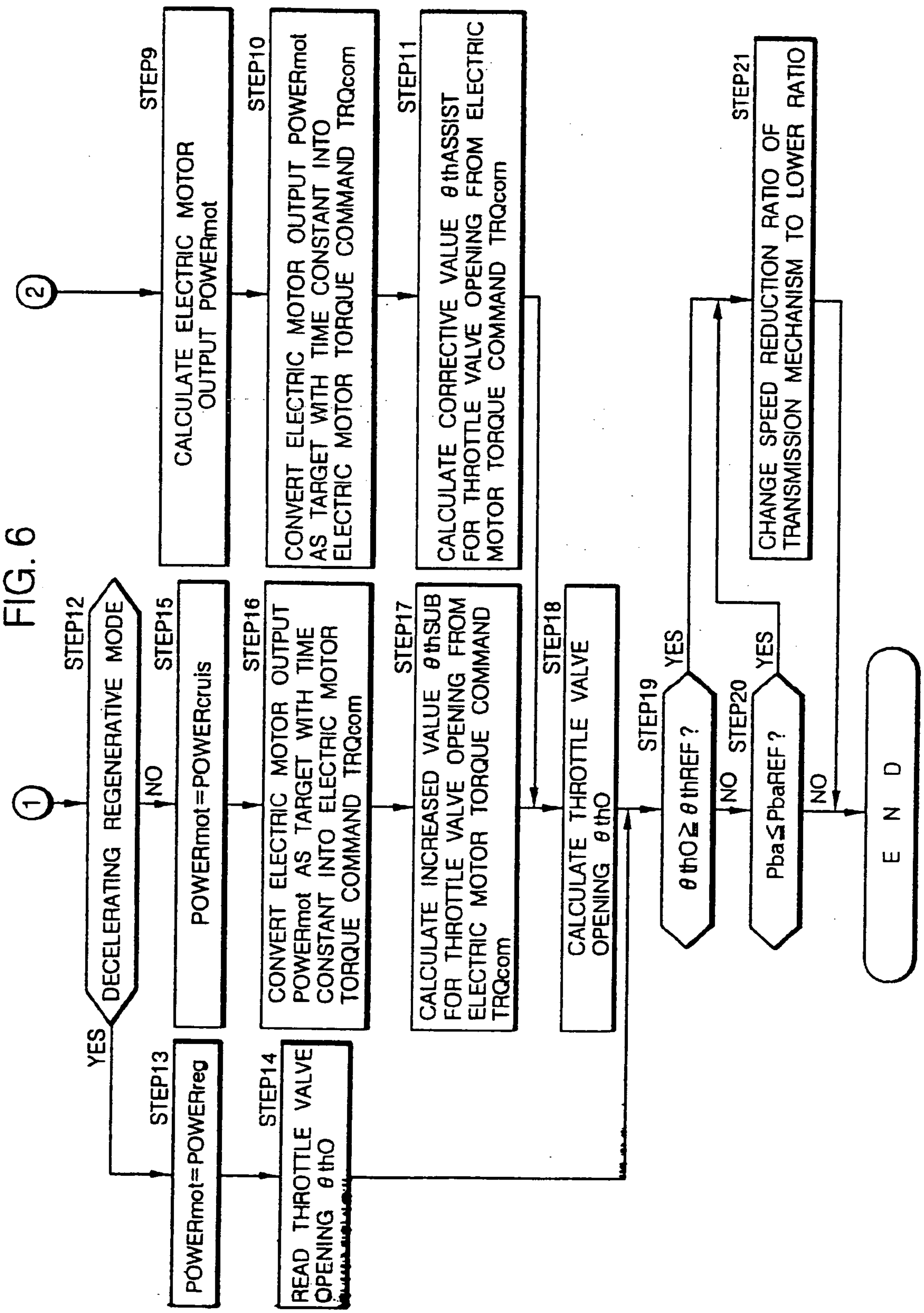

DRIVE POWER DISTRIBUTION PROCESS
STEP1
DETECT REMAINING CAPACITY OF ULTRACAPACITOR
STEP2
DETERMINE OUTPUT DISTRIBUTION QUANTITY PRATIO DEPENDING ON REMAINING CAPACITY
STEP3
DETERMINE THROTTLE VALVE OPENING COMMAND θthCOM
STEP4
DETERMINE DISTRIBUTION QUANTITY PRATIOth DEPENDING ON THROTTLE VALVE OPENING COMMAND θthCOM
STEP5
DETERMINE DEMAND DRIVE POWER POWERcom
STEP6
CALCULATE CORRECTIVE TERM θthADD FOR THROTTLE VALVE OPENING FOR GENERATING DEMAND DRIVE POWER POWERcom
STEP7
DETERMINE RUNNING STATUS QUANTITY VSTATUS
STEP8
VSTATUS>0 ?
YES
NO
1
2

FIG. 6



1
STEP12
DECELERATING REGENERATIVE MODE
YES
NO
STEP13
POWERmot=POWERreg
STEP14
READ THROTTLE VALVE OPENING θthO
STEP15
POWERmot=POWERcruis
STEP16
CONVERT ELECTRIC MOTOR OUTPUT POWERmot AS TARGET WITH TIME CONSTANT INTO ELECTRIC MOTOR TORQUE COMMAND TRQcom
STEP17
CALCULATE INCREASED VALUE θthSUB FOR THROTTLE VALVE OPENING FROM ELECTRIC MOTOR TORQUE COMMAND TRQcom
STEP18
CALCULATE THROTTLE VALVE OPENING θthO
STEP19
θthO≧θthREF ?
YES
NO
STEP20
Pba≦PbaREF ?
YES
NO
END
2
STEP9
CALCULATE ELECTRIC MOTOR OUTPUT POWERmot
STEP10
CONVERT ELECTRIC MOTOR OUTPUT POWERmot AS TARGET WITH TIME CONSTANT INTO ELECTRIC MOTOR TORQUE COMMAND TRQcom
STEP11
CALCULATE CORRECTIVE VALUE θthASSIST FOR THROTTLE VALVE OPENING FROM ELECTRIC MOTOR TORQUE COMMAND TRQcom
STEP21
CHANGE SPEED REDUCTION RATIO OF TRANSMISSION MECHANISM TO LOWER RATIO

FIG. 7

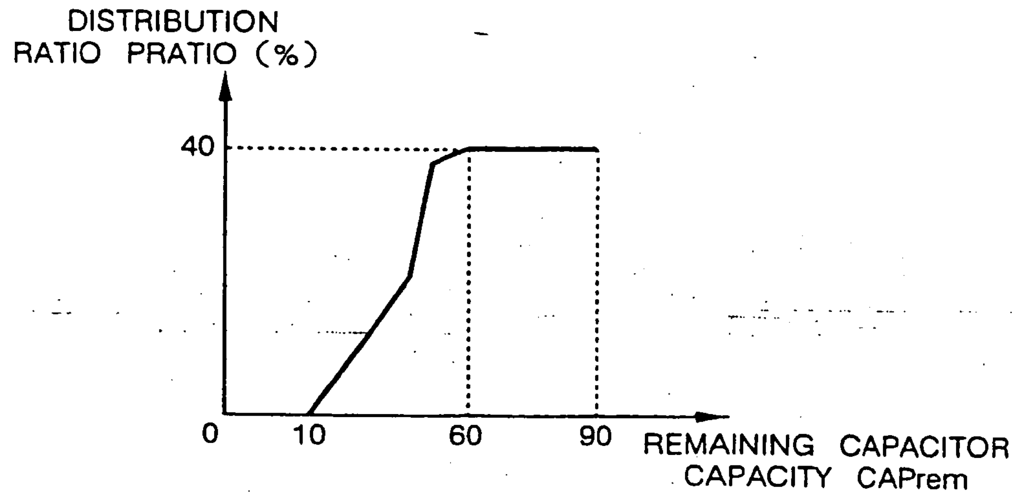

DISTRIBUTION
RATIO PRATIO (%)
40
0
10
60
90
REMAINING CAPACITOR
CAPACITY CAPrem

FIG.8

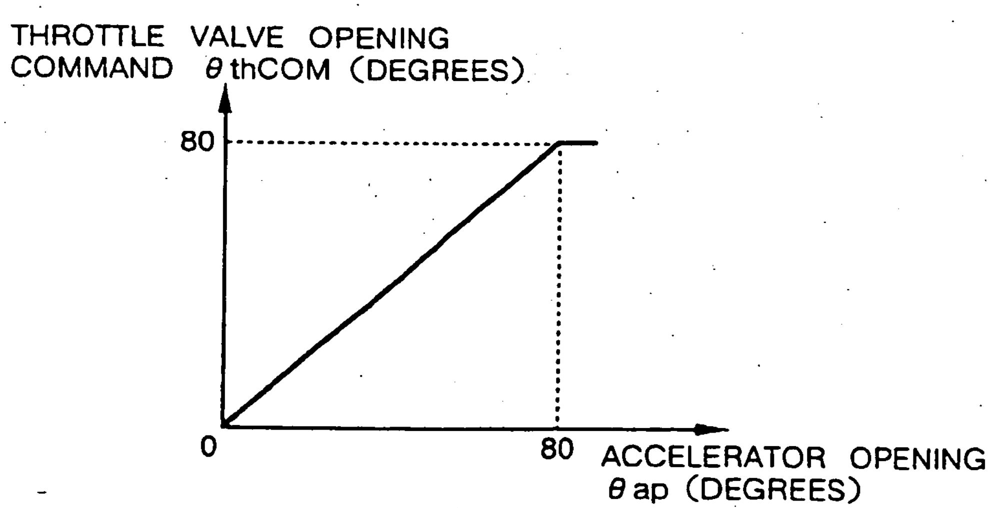

THROTTLE VALVE OPENING
COMMAND θthCOM (DEGREES)
80
0
80
ACCELERATOR OPENING
θap (DEGREES)

FIG. 9

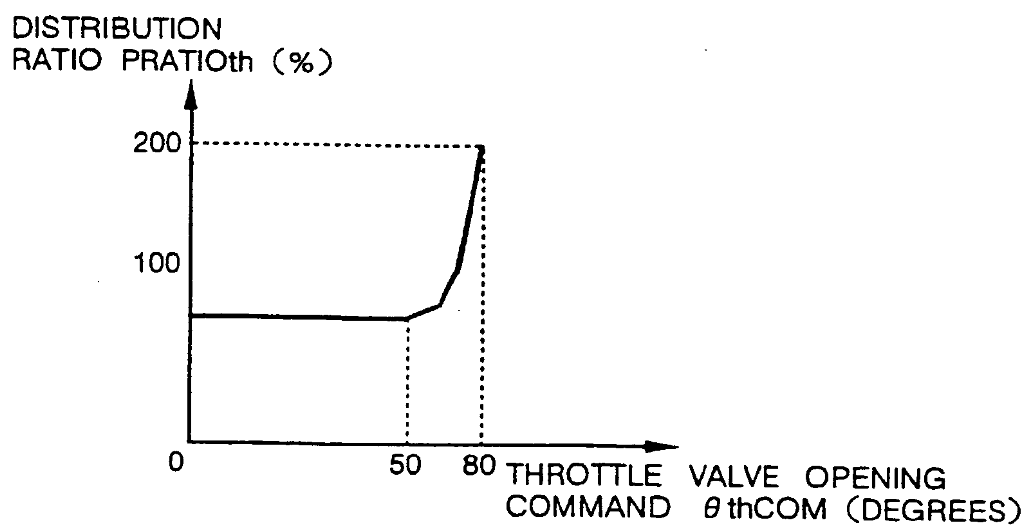

DISTRIBUTION
RATIO PRATIOth (%)
200
100
0
50
80
THROTTLE VALVE OPENING
COMMAND θthCOM (DEGREES)

FIG. 10

→ NE (rpm)

THROTTLE VALVE OPENING COMMAND θthCOM (DEGREES) ↓

	0	500		9500	10000
0					
1					
⋮			DEMAND DRIVE POWER POWERcom (KW)		
89					
90					

FIG. 11

→ VEHICLE SPEED (Km/h)

EXTRA OUTPUT POWERex (KW) ↓

	0	10		160	170
0					
1					
⋮			RUNNING STATUS QUANTITY VSTATUS (%)		
99					
100					

FIG.12

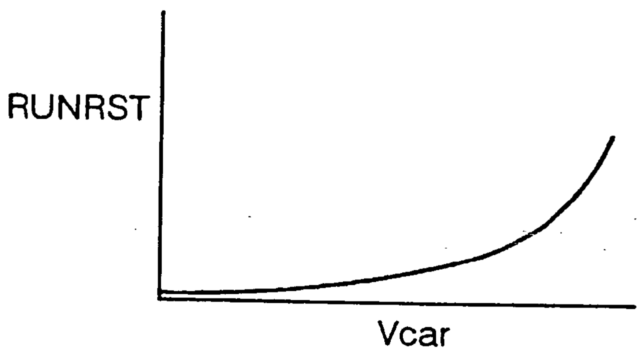

RUNRST
Vcar

FIG.13

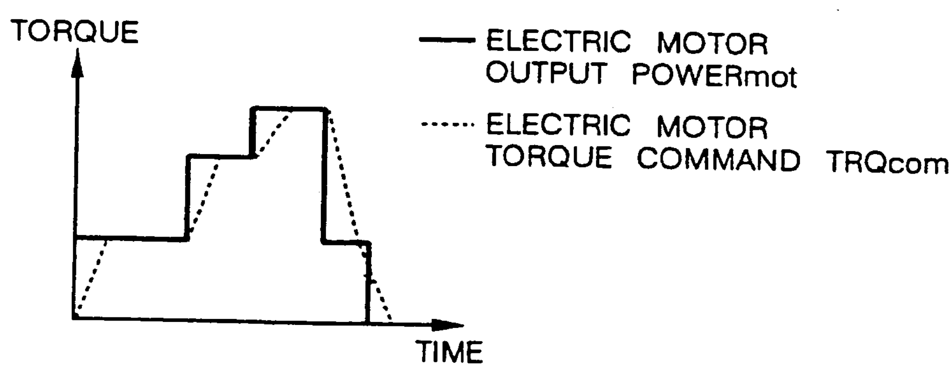

TORQUE
TIME
ELECTRIC MOTOR OUTPUT POWERmot
ELECTRIC MOTOR TORQUE COMMAND TRQcom

FIG. 14

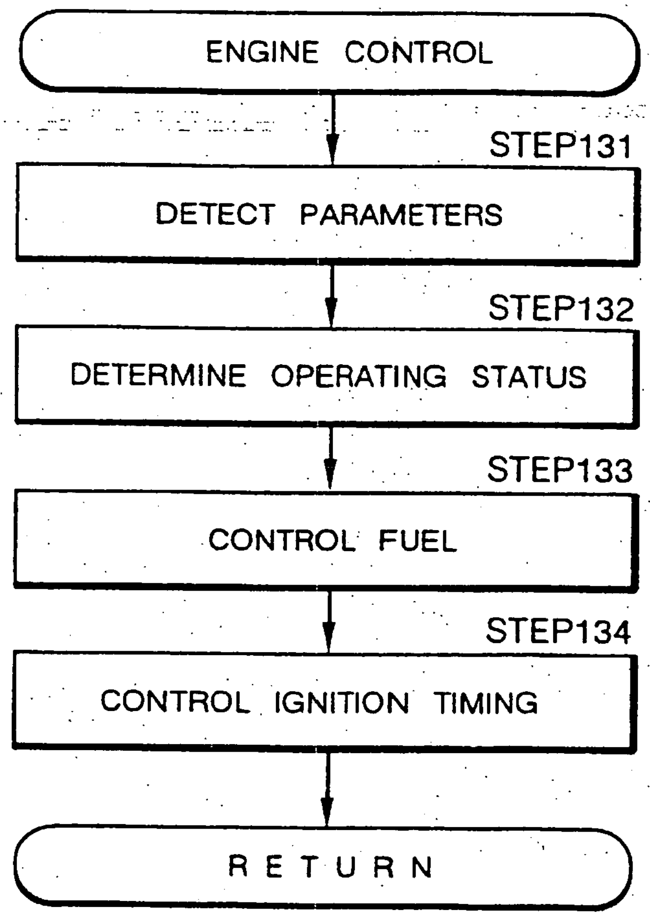

ENGINE CONTROL
STEP131
DETECT PARAMETERS
STEP132
DETERMINE OPERATING STATUS
STEP133
CONTROL FUEL
STEP134
CONTROL IGNITION TIMING
RETURN

FIG. 15

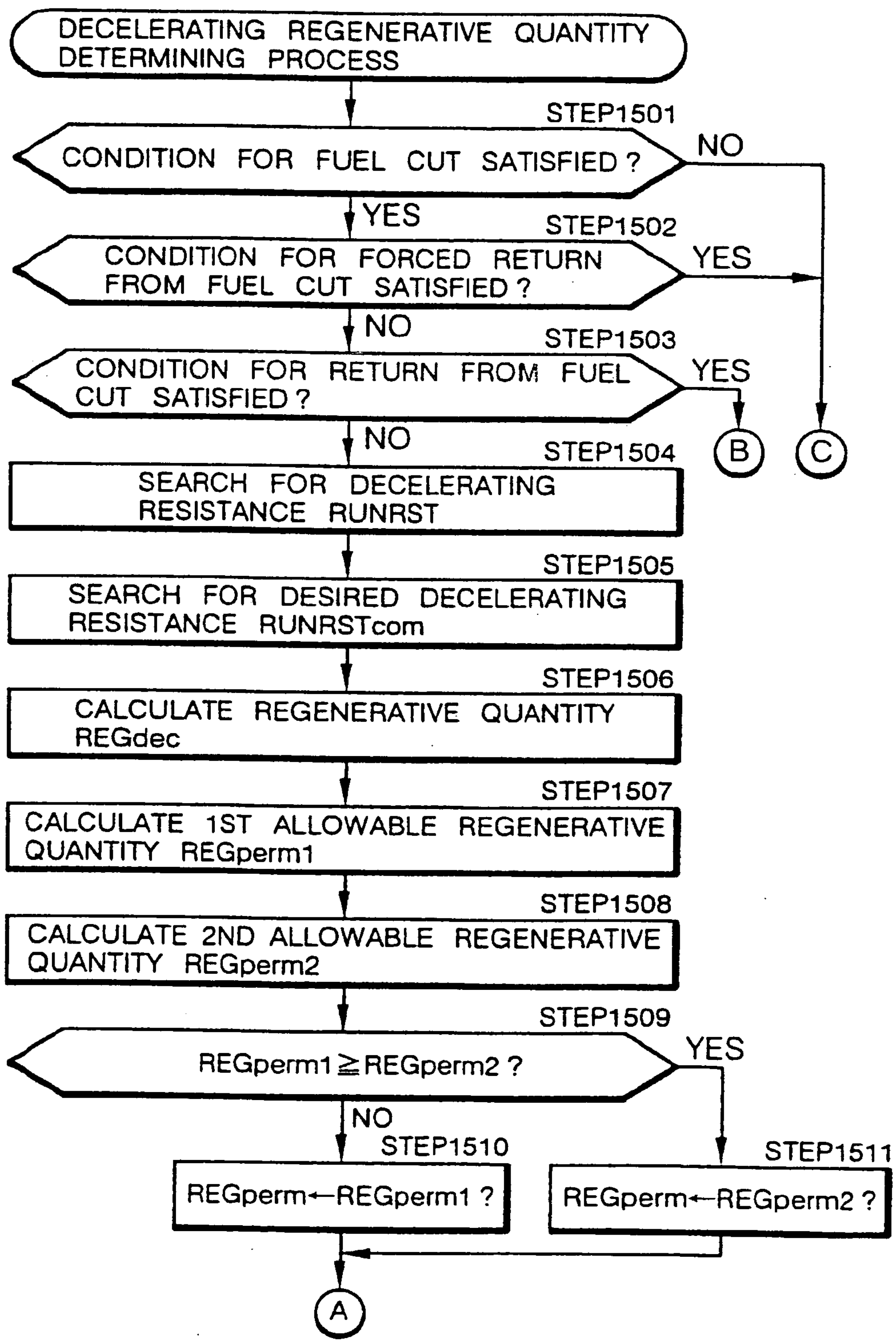

DECELERATING REGENERATIVE QUANTITY DETERMINING PROCESS
STEP1501
CONDITION FOR FUEL CUT SATISFIED ?
NO
YES
STEP1502
CONDITION FOR FORCED RETURN FROM FUEL CUT SATISFIED ?
YES
NO
STEP1503
CONDITION FOR RETURN FROM FUEL CUT SATISFIED ?
YES
NO
B
C
STEP1504
SEARCH FOR DECELERATING RESISTANCE RUNRST
STEP1505
SEARCH FOR DESIRED DECELERATING RESISTANCE RUNRSTcom
STEP1506
CALCULATE REGENERATIVE QUANTITY REGdec
STEP1507
CALCULATE 1ST ALLOWABLE REGENERATIVE QUANTITY REGperm1
STEP1508
CALCULATE 2ND ALLOWABLE REGENERATIVE QUANTITY REGperm2
STEP1509
REGperm1≧REGperm2 ?
YES
NO
STEP1510
REGperm←REGperm1 ?
STEP1511
REGperm←REGperm2 ?
A

FIG. 16

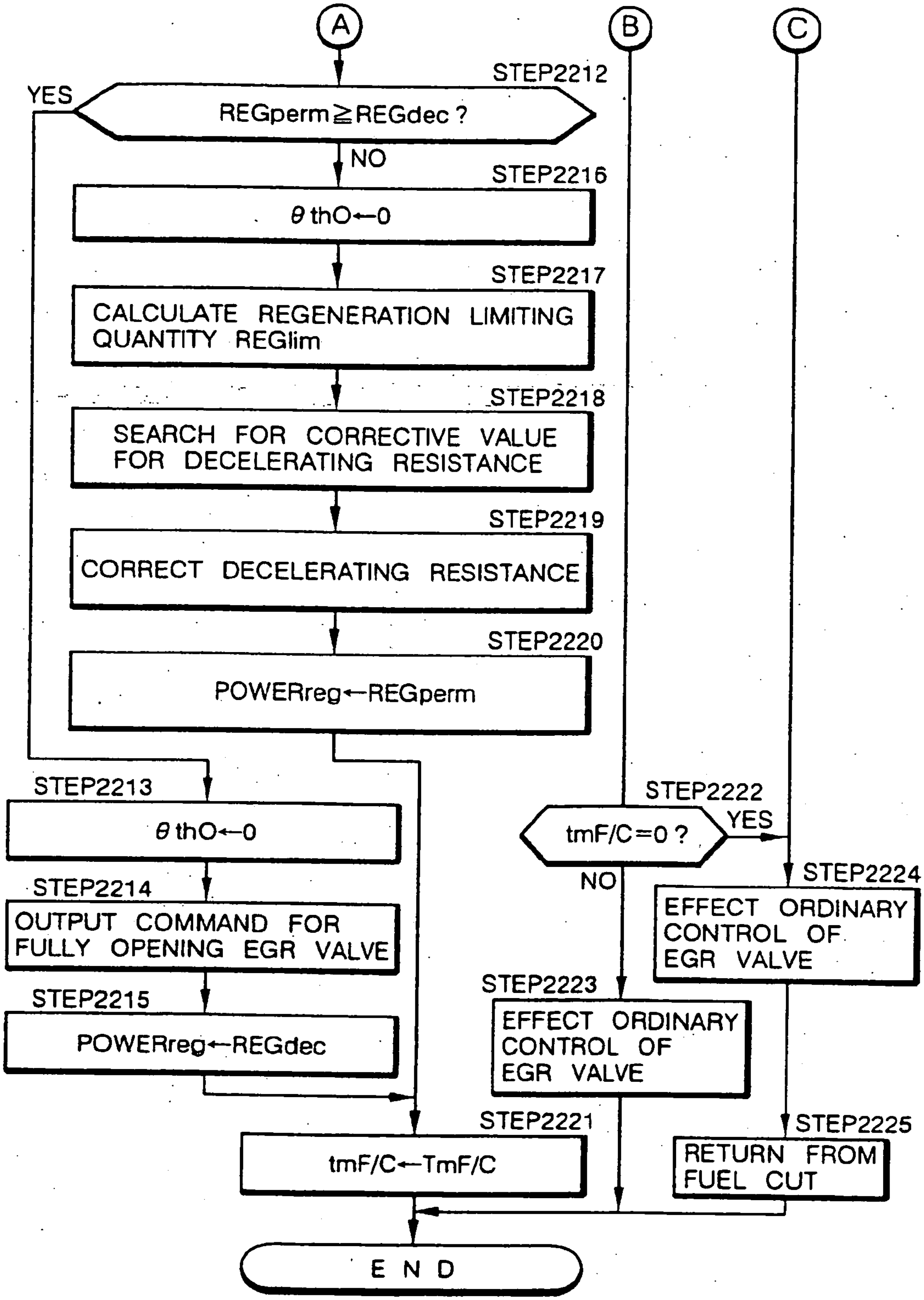

A
B
C
STEP2212
YES
REGperm≧REGdec ?
NO
STEP2216
θ thO←0
STEP2217
CALCULATE REGENERATION LIMITING QUANTITY REGlim
STEP2218
SEARCH FOR CORRECTIVE VALUE FOR DECELERATING RESISTANCE
STEP2219
CORRECT DECELERATING RESISTANCE
STEP2220
POWERreg←REGperm
STEP2213
θ thO←0
STEP2214
OUTPUT COMMAND FOR FULLY OPENING EGR VALVE
STEP2215
POWERreg←REGdec
STEP2222
tmF/C=0 ?
YES
NO
STEP2224
EFFECT ORDINARY CONTROL OF EGR VALVE
STEP2223
EFFECT ORDINARY CONTROL OF EGR VALVE
STEP2221
tmF/C←TmF/C
STEP2225
RETURN FROM FUEL CUT
E N D

FIG.17

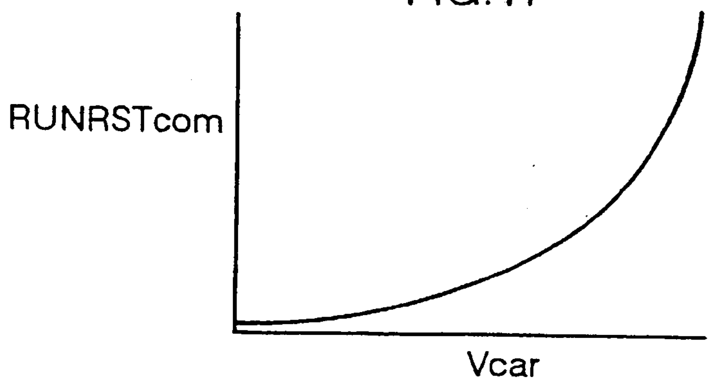


FIG.18

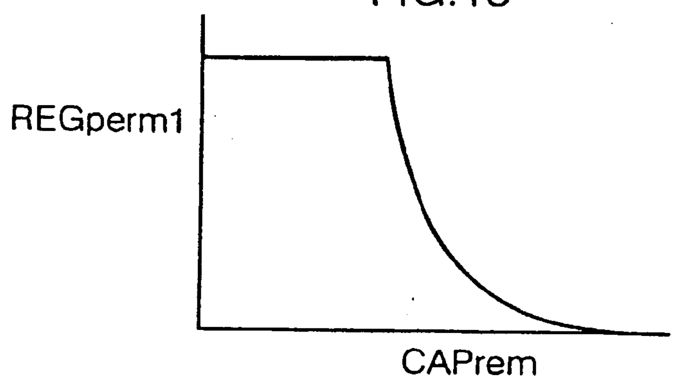


FIG.19

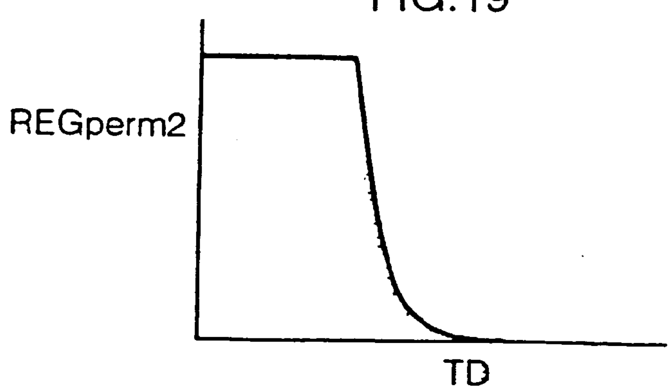


FIG. 20

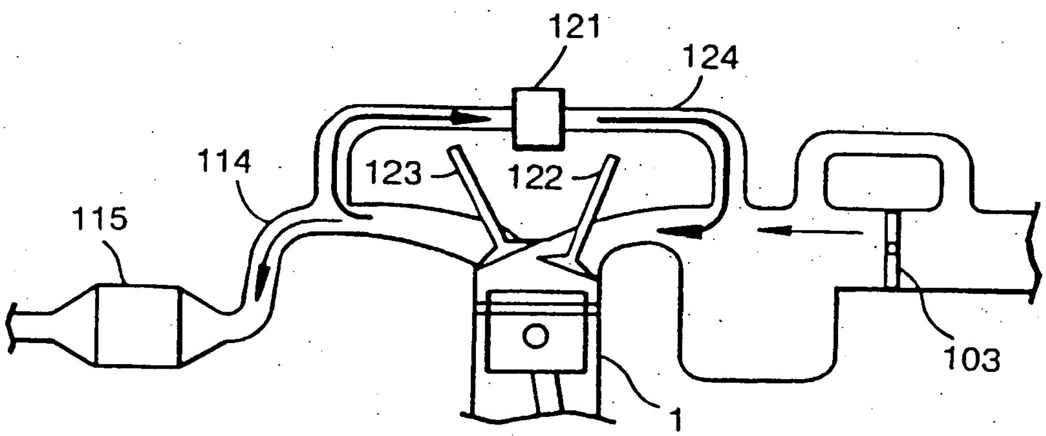


FIG. 21

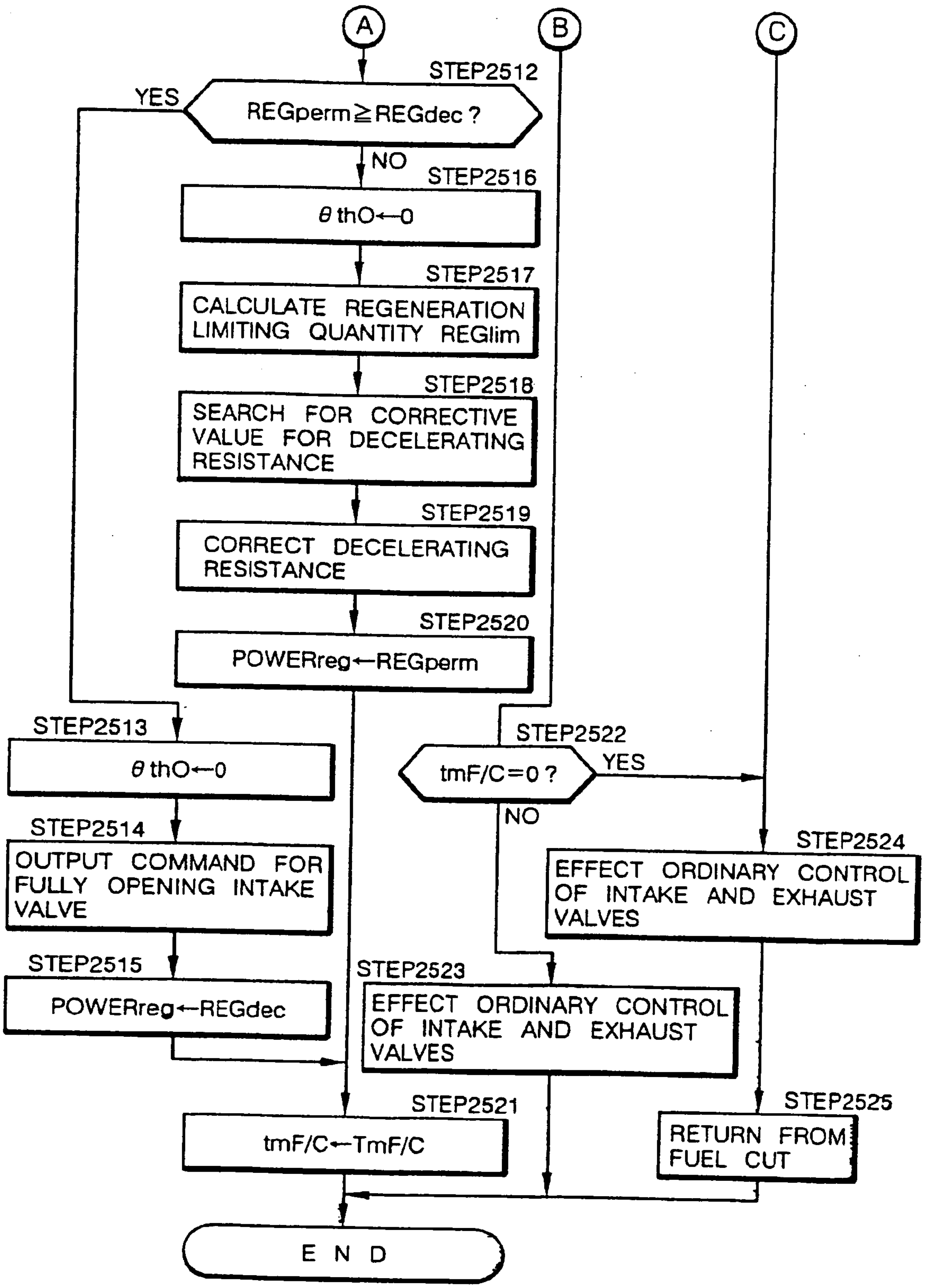

A
B
C
STEP2512
REGperm≧REGdec ?
YES
NO
STEP2516
θ thO←0
STEP2517
CALCULATE REGENERATION LIMITING QUANTITY REGlim
STEP2518
SEARCH FOR CORRECTIVE VALUE FOR DECELERATING RESISTANCE
STEP2519
CORRECT DECELERATING RESISTANCE
STEP2520
POWERreg←REGperm
STEP2513
θ thO←0
STEP2514
OUTPUT COMMAND FOR FULLY OPENING INTAKE VALVE
STEP2515
POWERreg←REGdec
STEP2522
tmF/C=0 ?
YES
NO
STEP2524
EFFECT ORDINARY CONTROL OF INTAKE AND EXHAUST VALVES
STEP2523
EFFECT ORDINARY CONTROL OF INTAKE AND EXHAUST VALVES
STEP2521
tmF/C←TmF/C
STEP2525
RETURN FROM FUEL CUT
E N D

FIG. 22

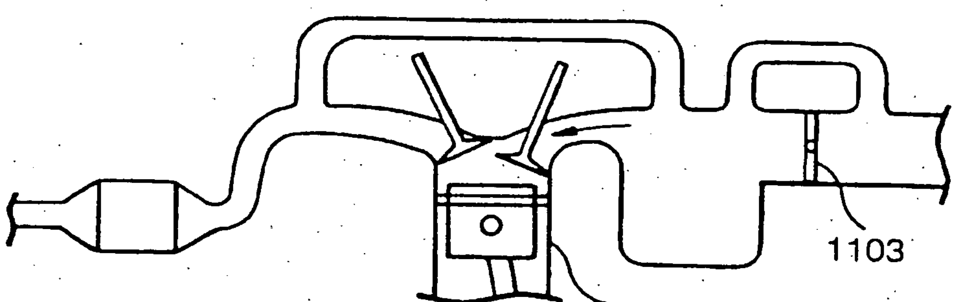


FIG. 23

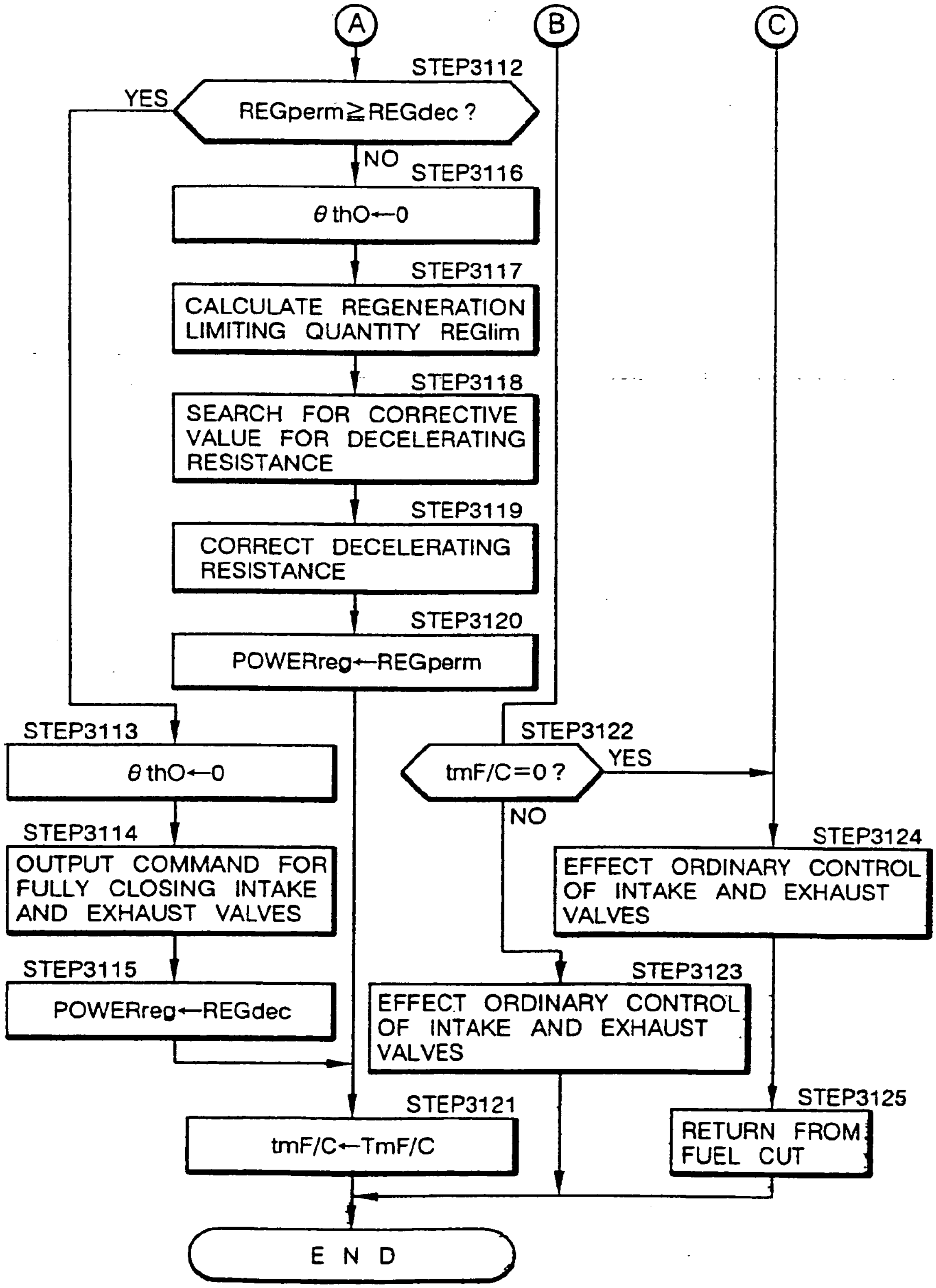
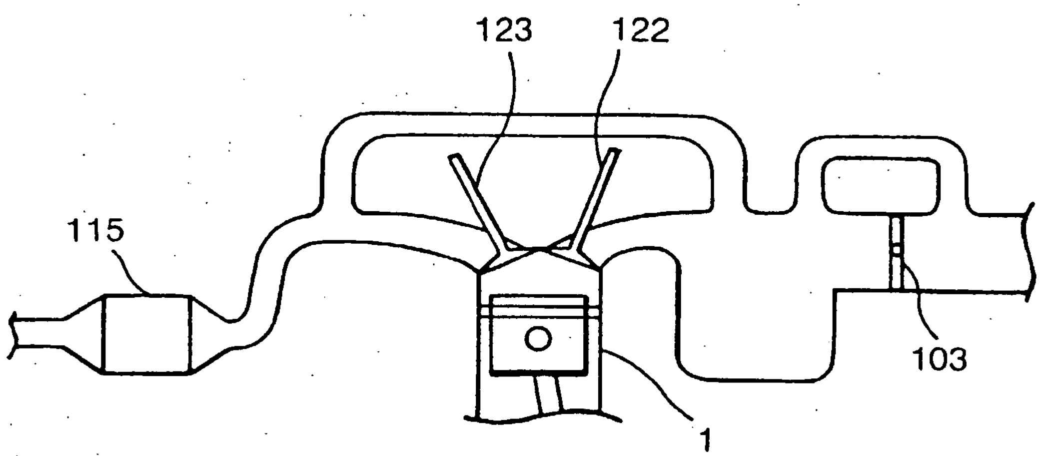

A
B
C
STEP3112
REGperm≧REGdec ?
YES
NO
STEP3116
θthO←0
STEP3117
CALCULATE REGENERATION LIMITING QUANTITY REGlim
STEP3118
SEARCH FOR CORRECTIVE VALUE FOR DECELERATING RESISTANCE
STEP3119
CORRECT DECELERATING RESISTANCE
STEP3120
POWERreg←REGperm
STEP3113
θthO←0
STEP3114
OUTPUT COMMAND FOR FULLY CLOSING INTAKE AND EXHAUST VALVES
STEP3115
POWERreg←REGdec
STEP3122
tmF/C=0 ?
YES
NO
STEP3124
EFFECT ORDINARY CONTROL OF INTAKE AND EXHAUST VALVES
STEP3123
EFFECT ORDINARY CONTROL OF INTAKE AND EXHAUST VALVES
STEP3121
tmF/C←TmF/C
STEP3125
RETURN FROM FUEL CUT
E N D

FIG. 24



European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 30 7545

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	PATENT ABSTRACTS OF JAPAN vol. 097, no. 005, 30 May 1997 -& JP 09 004479 A (TOYOTA MOTOR CORP), 7 January 1997 -& US 5 725 064 A (IBARAKI RYUJI ET AL) 10 March 1998 * abstract * ---	1-7	B60K41/00 B60K13/00 B60K6/04 F02M25/07
P,X	PATENT ABSTRACTS OF JAPAN vol. 098, no. 004, 31 March 1998 & JP 09 329060 A (TOYOTA MOTOR CORP), 22 December 1997 * abstract * -----	1	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			B60K F02M

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
BERLIN	18 December 1998	Wiberg, S

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